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# The Canadian Entomologist

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No. 6

## Life History and Sex Determination in the Diaspine Scale, *Pseudaulacaspis pentagona* (Targ.) (Coccoidea)

By FREDERICK D. BENNETT<sup>1</sup> AND SPENCER W. BROWN<sup>2</sup>

The increasing body of knowledge about the armored scales is beginning to reveal many unique aspects in the life cycles of these highly specialized insects. Such information is not only of value to the entomologist and those concerned with the control of scales but is also becoming important in such diverse fields as genetics, ecology, cytology, and physiology; armored scales may well find an expanding place in the laboratory as subjects for researches in a variety of fields. *Pseudaulacaspis pentagona* (Targ.) has one of the most unusual, yet to date one of the best understood life cycles of the armored scales. Various aspects of its biology have been described by Berlese (1910), Smit (1953), Dustan (1953), and Monti (1955). Accounts of its natural enemies or biological control programs have been given by Berlese (1910) for Italy, by Ogilvie (1928) and Simmonds (1955) for Bermuda, by Bennett (1956) for Trinidad, and Clausen (1956) for Florida. *P. pentagona* is a pest of economic importance on a wide variety of hosts throughout an extensive geographic distribution (Anon., 1956), and has been cultured extensively in the biological control laboratory for the mass-rearing of scale parasites and predators. Recent investigations of the sex determining mechanism and chromosome behaviour (Brown and Bennett, 1957) have again shown unusual processes and relationships, some of which appear to occur in many other species of armored scales. It is the purpose of this paper to describe the life cycle of *P. pentagona* as it is known from field and laboratory studies and from cytological and genetic investigations.

### Duration of Stages

*P. pentagona* was apparently first reared on potato tubers by E. C. G. Bedford at the Bermuda Department of Agriculture in 1948. Subsequent mass culturing in Bermuda (Dustan, 1953) and in Trinidad at the Commonwealth Institute of Biological Control has provided further information.

The female deposits her entire complement of eggs within a period of 8 or 9 days and the individual egg hatches within 3 to 4 days after it is laid. The crawlers settle and begin to feed within 48 hours after hatching. The first nymphal stage is completed in both sexes on the seventh to eighth day after hatching. The female is sexually mature after the second and final moult which occurs on the nineteenth or twentieth day. The exuviae and circular scale covering are typical of the diaspidine scales.

After the first moult, the male begins construction of an elongate white covering, typical of those armored scales in which the male covering is not simply a smaller, elongate modification of that of the female. A second moult occurs on the twelfth day and the adult male appears on the nineteenth or twentieth day. The adult males usually emerge in the late afternoon or evening and die within 24 hours. The male is capable of copulation shortly after emergence; unions are of short duration and the male may mate with a number of females.

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Fertilization takes place while the eggs are still in the egg follicles; there is but one egg per follicle, and the isolated ovarian apparatus resembles two clusters of grapes. The eggs undergo considerable development before oviposition which usually commences 14 to 16 days after mating.

The duration of the life cycle is influenced by temperature. In Trinidad and in Bermuda during the summer and under temperature control (25°C) the time between generations was 36 to 40 days. In the cooler winter months in Bermuda, a generation required 80 to 90 days. Monti (1955) recorded 3 generations a year in Italy; the adults of the third generation remained in a resting stage from October to April.

#### Behavior of Unmated Females

When females are isolated to prevent mating, they produce an extra covering to one side of the typical scale already present. Construction of the new covering begins 3 to 4 days after the females achieve sexual maturity, and individual females vary considerably in the rate at which they work.

The new covering differs markedly from the typical scale and is white in color and loose in texture. According to Dickson (1951), *Aonidiella aurantii* (Mask.) includes part of the superficial plant substance in the manufacture of the scale and, on the basis of color, such inclusion seems also to be true of the original scale of females of *P. pentagona*. The secondary covering, however, is not closely attached to the potato surface and seems not to include any of the plant material.

As the secondary covering is constructed, the female moves out from under the original scale until she is protected only by the new material which is frequently more extensive than the original scale. Apparently the proboscis elongates during this movement as it continues to remain inserted in the original feeding puncture. Females which are mated while the new covering is incomplete will cease to produce it on the following day. Later, they will add a small lip or shelf under which the eggs will be protected. If not mated by the twentieth day, the female stops work on the new covering, but continues to move so that she may soon be completely exposed. She presumably becomes more accessible to males, but it is not known whether males are more apt to copulate with such females than with those protected by a covering.

When mating was delayed for 20 days, oviposition commenced 9 to 11 days later, an interval about 3 days less than that following matings at sexual maturity. In another experiment, virgin females isolated for 40 days past the time of normal mating died without ovipositing. This and subsequent experiments have demonstrated conclusively that mating is necessary for the production of progeny.

Stafford (1947) reported the formation of a similar accessory scale covering by unmated females of *Parlatoria oleae* (Colvée), the occurrence of females outside this covering and the necessity of mating for the production of progeny. This is apparently the only other scale where the production of an accessory covering as a consequence of delayed mating has been reported. The reduction of time between mating and oviposition as a result of delayed mating has not been noted in scales other than *P. pentagona*. Quayle (1938) observed that females of *A. aurantii* will remain in the "grey adult stage" for as long as six months if mating is prevented.

#### Sexual Dimorphism and Dichronism

The eggs and crawlers of *P. pentagona* are sexually dimorphic by virtue of a difference in color. Eggs containing female embryos are coral in color when laid while those with male embryos are pinkish white. Both sexes darken somewhat during the first day or two, and the female embryos, which may at first



appear mottled, become uniformly colored. In both sexes, the intensity of color may vary considerably but there are extremely few cases in which the eggs cannot be separated into two well-defined, non-overlapping classes.

The color difference persists during the crawler stage up to the end of the first instar. As the coverings produced by second instar males and females differ according to sex, it is possible to sex an individual quite readily at any stage of its development. Sexing of the eggs and crawlers on the basis of color differences was first demonstrated by Bedford in Bermuda, and repeated by Bennett in Bermuda and Trinidad. The two classes of eggs or crawlers were isolated individually on potato tubers and permitted to mature.

The mothers first deposit all the eggs which contain the coral-colored female embryos and follow directly with those containing the pinkish-white male embryos. This interesting example of sexual dichronism has been readily demonstrated in both individual scales and the mass-rearing program. A female will continue to oviposit after the scale is carefully removed; as they emerge, the eggs adhere end to end to form chains of 7 to 8 before movement of the mother breaks the chain. By periodically removing the eggs already laid, it is possible to determine precisely the change over from coral to pinkish white eggs.

In the mass rearing programs, sexual dichronism can be utilized to infest trays of potatoes almost exclusively with either female or male crawlers. The cycle is started with a culture of uniformly aged scales; during the first 2 or 3 days of crawler production, new trays can be infested with female crawlers, and with male crawlers during the last 2 or 3 days.

In a study of the biology of *Diaspis* (= *Pseudaulacaspis*) *pentagona* Targ. in the Romagna region of Italy, Monti (1955), recognized two main color groups in the eggs, orange and creamy white; a third group had eggs of intermediate straw-yellow color. Eggs of the orange class proved to be female while those of the creamy-white class were males. Those of intermediate color were of both sexes. Monti found that individual females produced eggs of one, two, or all three color groups; he also noted that a female would lay a small group of eggs of one color and then another small group of a different color but he does not indicate that the eggs were produced in the strict female-male sequence found in Bermuda and Trinidad.

According to Smit (1953), *P. pentagona* produces only bright yellow eggs in South Africa. However, Bedford (personal communication, 1957) states that two color groups occur in the South African representatives. At the present, it seems safest to conclude that *P. pentagona* varies or may vary geographically in regard to sexual dimorphism and dichronism.

To the author's knowledge, no other occurrences of sex difference in egg color have been found among the armored scale insects. DeBach and Fisher, (unpubl.) tested the bisexual strain (see De Bach and Fisher 1956) of *Aspidiotus bederae* (Vallot) for dichronism with negative results; females of a uniform age produced about the same number of offspring of each sex on each day of the twenty day laying period for the test.

#### Sex Differences in Crawler Behaviour

Female crawlers are much more active than male crawlers. While the males tend to settle close to the parent scales shortly after hatching, the females wander about for several hours. In mass cultures where one tray of potatoes is infested by crawlers dropping from a tray above, the female crawlers are usually uniformly dispersed while the males are largely restricted to the upper surfaces where they first fall (see Dustan, 1953, for culture methods).

The crawlers of both sexes are positively phototropic, and this tropism, coupled with the greater activity of the female crawlers would seem to account for the distribution of the scale on recently infested plants in the field. Infestations usually begin at the base of the plant. In the succeeding generation, the developing males are clustered immediately above the base whereas the females are scattered further up the stem. Although less noticeable in later generations, small patches of male scale coverings will indicate the position of females of the previous generation.

#### Cytological Observations

In 1954, Lindner reported a haplodiploid sex differential in *Aspidiotus* (= *Quadraspidiotus*) *perniciosus* Comst. which has 8 chromosomes in the female and 4 in the male. He assumed that the males developed from unfertilized eggs, according to the Dzierzon scheme.

Brown and Bennett (1957) found *P. pentagona* also to be a haplodiploid species with 16 chromosomes in the female and 8 in the male. Since fertilization is required for the production of offspring, the males could not be arising, in an uncomplicated fashion, from unfertilized eggs. Cytological studies showed that male haploidy was a consequence of chromosome elimination during early embryogeny. At late cleavage, one haploid set of 8 chromosomes is eliminated, during a mitotic cycle, from all or nearly all the diploid cells of the embryo. X rays were used to fragment parental chromosomes. Broken chromosomes were found in the haploid embryos after irradiation of the mothers but not after treatment of the fathers, whereas they appeared in the diploid embryos after treatment of parents of either sex. It could thus be demonstrated that the eliminated chromosomes were of paternal origin.

Another interesting feature of the cytology is the part played by the polar bodies in embryonic development as has been previously reported for several other coccids (Hughes-Schrader, 1948). Two polar bodies are formed, but are not cast off. The oocyte begins reduction division with the 16 chromosomes paired in 8 bivalents. The first polar body receives 8 chromosomes or 16 chromatids, and the chromatids slowly separate to give a nucleus of 16 chromosomes. The second polar body receives 8 chromosomes. The polar bodies or polar "nuclei" remain quiescent, close together near the distal end of the egg during the first few cleavages. Soon, a cleavage nucleus becomes located near the polar bodies and the three combine to form a pentaploid nucleus of 40 chromosomes: 16 from the first polar body; 8, second polar body; 16, cleavage nucleus. The pentaploid nucleus then divides to initiate the formation of a polyploid sector in the embryo. Although the subsequent fate of the polyploid cells was not traced, it seems likely, on comparison with other coccids, that these become the mycetocytes.

Cytological details of the embryology are summarized in fig. 1. As has already been noted, meiosis in the female is normal. The spermatogenic division in the haploid male is a simple mitosis, as is commonly observed in haplodiploid insects, and each spermatocyte yields two sperm cells.

The mechanism of chromosome elimination described in this section determines whether a haploid, male embryo or a diploid, female embryo will be produced. The problem of what, in turn, is determining elimination, and therefore "predetermining" sex will be considered in the next section.

#### Sex Ratios and Sex Determination

As determined from eggs and crawlers collected from females undisturbed during oviposition, the sex ratio of *P. pentagona* is close to 1:1; however, the

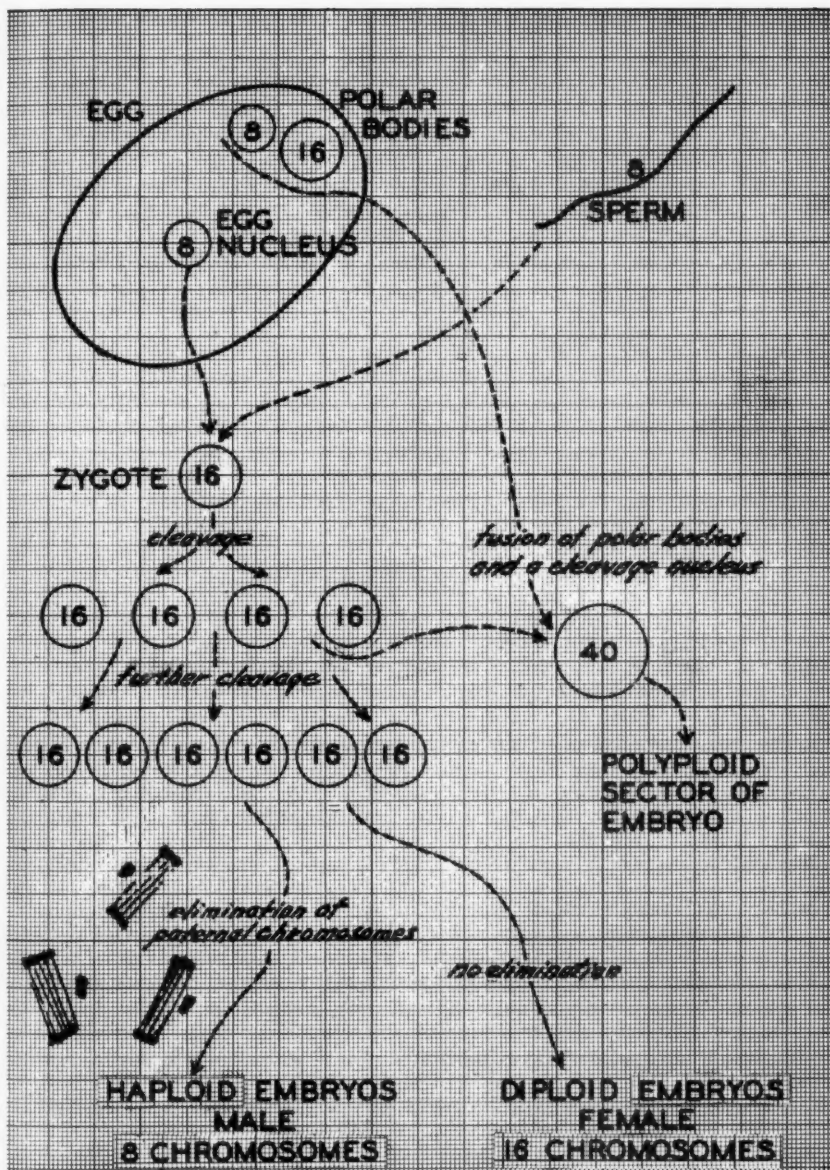


Fig. 1. Diagram of cytological events in the life cycle of *P. pentagona*. The numbers indicate the chromosome numbers of the respective nuclei. Polyploid sectors are found in both male and female embryos.

ratio may vary widely, and certain females may produce nearly all sons or nearly all daughters. The first studies on sex ratio were made in Bermuda; those made later in Trinidad gave a higher proportion of females but different methods were used. In the Trinidad series, the scale coverings were carefully removed at the onset of oviposition and the eggs removed after the daily records had been made. Removal of the covering may have led to desiccation and an earlier death; any abnormal cessation of egg production would obviously favor a higher relative proportion of female progeny since the males always appear last. The records (Table 1) show a marked fluctuation in sex ratios from the different mothers; female 4, for example, produced a preponderance of sons whereas the average for the group was 1.8:1 in favor of daughters.

Working with *Pseudococcus* (= *Planococcus*) *citri* (Risso), James (1937, 1938) demonstrated that females that had been aged prior to mating would eventually produce a preponderance of sons. The modification of the sex ratio was proportionate to the period of delay and could not, at least for the earlier period, be explained as the result of a differential mortality.

To determine the effects of delayed mating in *P. pentagona* three potatoes infested with second stage females were isolated in tightly screened jars and mating delayed for twenty days. Twelve females were isolated and their progeny sexed. Three of the females laid a few coral (female) eggs and then numerous pink eggs (male). The other nine laid only pink eggs (see table 2, Brown and Bennett, 1957). Fourteen other females were discarded after they had laid twenty to thirty male eggs and no female eggs. Thus maternal aging prior to mating increases the sex ratio in favor of the males.

The marked effect of aging the mothers on sex ratio and the fact that the male offspring are always produced last have led to the conclusion that physiological factors in the ovary determine whether or not the chromosomes are eliminated and thus whether a male or female embryo will result, (Brown and Bennett, 1957). With such a system, genetic factors of the mother could affect the sex ratio through their influence or control of the physiological factors. Genetic factors directly or indirectly influencing chromosome behaviour are not, however, primary sex factors in that they do not directly determine the sex of the offspring. It is believed that the sex of the individual is finally determined by the genetic balance of the haploid and diploid states according to some such scheme as that set forth by Schrader and Sturtevant (1923) or, more recently, by DaCunha and Kerr (see Kerr and Laidlaw, 1956).

In her discussion of James' (1937, 1938) experiments with *Pseudococcus*, both in regard to aging of females and variation in sex ratio, Hughes-Schrader (1948), suggests that sex is weakly determined by genetic factors which may be overridden by environmental influence. The explanation offered above fits, in a general way, with that suggested by Hughes-Schrader. In other species of scales which may prove to be haplodiploid but lacking sexual dichronism (a characteristic which, it seems, may be rather rare among the scales), it will be of great interest to see what sorts of influences are important in "predetermining" sex.

#### Comparison with Other Species

*P. pentagona* is the only species for which sexual dichronism and sexual differences in egg color have been reported. Other species of scale may have white (uncolored) eggs or may show darkening of color between laying and hatching.

A cytological survey of the armored scales which is still in progress shows

that the haplodiploid scheme is probably typical of the scale insects (Brown and Bennett, 1957; Brown, unpublished). Table 2 summarizes the results to date of the survey; obviously, only a very small portion of the thousands of species has yet been investigated. All but three of the bisexual species are haplodiploid, and there is no reason to assume that the unisexual species were not derived largely from the majority class of bisexual species. These three species show a complex chromosome behaviour in the male similar in some ways to that described for several "lecanoid" families of coccids (Hughes-Schrader, 1948); this system has been described in summary form for *Comstockiella sabalis* (Comst.) (Brown, 1957), and will not be further considered in the present report.

Chromosome elimination figures, or individual embryos with both the haploid and diploid numbers (thus indicating elimination to be in progress) have been noted in about half the bisexual species even though it has not been the purpose of the survey to make a complete cytological study of each species, some of which have been represented by very scanty material. It seems reasonable to assume that elimination is the typical method of producing haploid embryos in the armored scales; however, the possibility of development of haploid embryos from unfertilized eggs should be kept in mind.

#### Summary

The life cycle of *Pseudaulacaspis pentagona* (Targ.) shows several unusual features. The females produce all their daughters first and then all their sons (sexual dichronism); the sexes can be differentiated by color: the eggs with female embryos are coral and those with male embryos are pinkish-white; the crawlers maintain the same color differences. Unmated females build an extra protective covering, different in color and texture from that of the typical scale; after aging as virgins, the females will, after mating, produce a preponderance of sons. No progeny is produced without mating.

Sex determination follows a haplodiploid scheme. The male embryos, however, do not arise from unfertilized eggs but achieve their haploidy through elimination of the paternal chromosome set at late cleavage. This system of chromosome behavior may prove to be characteristic of the majority of armored scales although only a small percentage has as yet been investigated cytologically. One other type of chromosome mechanism is known in three species and still others may be discovered.

Duration of stages, behavior of crawlers on infested plants, and the application of sexual dichronism to mass rearing techniques are described.

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**A Note on *Megachile inermis* Prov. in Trap-nests in Wisconsin  
(Hymenoptera: Megachilidae)**

By J. T. MEDLER<sup>1</sup>

Records of *Megachile inermis* Prov. in trap-nests are given in order to supplement previous reports on the nesting biology of the species. In Saskatchewan, Peck and Bolton (1946) did not obtain nests in 1943 with 1/4-inch holes bored in logs, but were successful in 1944 with 5/16-inch holes. The cells in 14 nests averaged 4.2, range 2 to 7, and their rearings produced 10 males and no females. In Manitoba, Stephen (1955) associated the nesting of *M. inermis* with burnt-over or waste poplar. The bee utilized the poplar after the trees had decayed sufficiently to permit the bee to burrow into it. He found no indication of nesting in borer tunnels, but reported that the bees themselves excavated tunnels from a crack or crevice or the exposed end of a log. Stephen (1956) described the excavating activity of the bee in poplar, and reared 3 males from cells transferred to glass tubes.

In Wisconsin, thirty-two nests of *M. inermis* were obtained from 1952 to 1956 inclusive in sumac-stick trap-nests of the type described by Medler and Fye (1956). They were obtained in Bayfield, Ashland and Iron counties in northern Wisconsin and at the Council Grounds State Forest near Merrill, at approximately 45° north latitude. The latter site provided 15 nests, and the abundance may have been associated with the common occurrence of *Populus tremuloides* Michx., at that trapping site. The bees nested in 5/16-inch (7.8 mm.) borings, but did not utilize the 1/4-inch borings which were equally available for nesting. Nests were constructed in July and August. When the trap-sticks were split open in late summer, each nest was found with larvae destined for an overwintering generation. Therefore the species has one generation each year.

Typical nests in a 5/16 x 6-inch hole are shown in Figure 1. The average number of cells in the 32 nests was  $6.3 \pm 2.44$ , ranging from 1 to 12. The foundress bees made elaborate protective plugs with leaf pieces, chewed leaf, sawdust, rotting wood, moss, soil, and sand grains in various combinations. Usually circular-leaf pieces were used to construct an orifice plug and a plug adjacent to the last provisioned cell. The leaf pieces were cemented together tightly, and sometimes both sand grains and pieces of chewed leaf were incorporated. These plugs, which were very hard, were 10-15 mm. thick, but occasionally were thinner. The space between the circular-leaf plugs was loosely packed with sawdust, moss, or rotting wood so that the overall length of the protective plug ranged from 1 1/2 to 2 1/2 inches.

The thimble-shaped cells were made with leaf pieces 17-20 mm. long and 9-12 mm. wide. The oblong pieces were intermixed with one or two circular-leaf pieces approximately 7 mm. in diameter. Leaf pieces used in the construction of 27 cells averaged  $7.7 \pm 1.67$ , range 5-11. The cells were capped with 5-7 circular-leaf pieces after provisioning with pollen and nectar was finished.

Individual cells were transferred to glass vials for laboratory rearing. Data from representative nests are given in Table 1. A high ratio of males to females is suggested by these data, and also by the fact that 42 males but only 14

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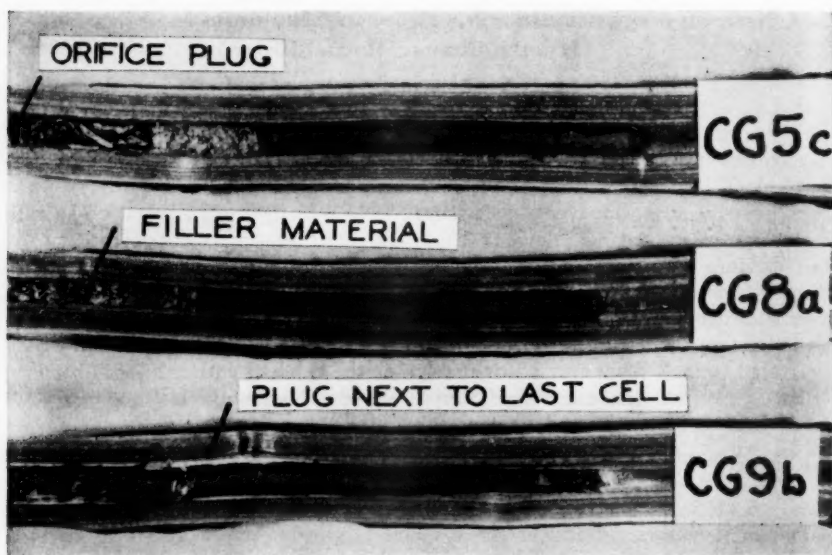


Fig. 1. Nests of *M. inermis* in sumac trap-sticks, showing arrangement of cells and protective plugs.

females were obtained in all rearings. This high ratio of males is consistent with published records, but the distribution of the sexes in nests 4, 7, and 14 appears equal. It would be premature at this time to conclude that an unequal sex ratio exists in nature.

*Coelioxys lucrosa* Cress. was reared from nests 13 and 14. In nest 12, the attack by *Leucospis affinis* Say resulted in the loss of all bees in the nest. The long orifice plug made by *M. inermis* probably would prevent effective oviposition of *L. affinis* in nests in logs.

Many gaps in the rearing data resulted from either contamination by the parasite, *Melittobia chalybii* Ashm., in incubators, or from cells which were unsuitable for rearing due to a moldy condition when the nests were opened. Large numbers of *M. chalybii* were reared from each bee. In 4 cells where the host was entirely consumed, the total number of parasites was 211, 267, 329 and 451, respectively. It was not possible to determine the per cent of parasitism in the field because of the laboratory contaminations.

Rearing mortality also resulted from unfavorable conditions during time-temperature studies. Research on terminating diapause in larvae was not conclusive as adults emerged from cells held at 4.5° C. for 5, 12, 33, and 41 days.

*M. inermis* infrequently visits alfalfa in Wisconsin and rarely trips the flowers. It prefers to visit fireweed and thistles (*Cirsium vulgare* (Savi) Tenore, *C. altissimum* (L.) Spreng. and *C. arvense* (L.) Scop.). Specimens also have been collected on flowers of wild rose, sumac, sunflower, burdock and diervilla. Foraging preference on thistles and fireweed was reported by Peck and Bolton (1946). Stephen (1955) observed *M. inermis* tripping alfalfa but considered the species of little benefit where competing bloom was abundant

TABLE 1

Rearing record of *Megachile inermis* Prov. from fourteen trap-nests; showing sex of emerging bees, cell sequence and parasitism

Nest Number	Cell Number										
	1	2	3	4	5	6	7	8	9	10	11
1	♂										
2	♂	†									
3	♀	♂	♂								
4	♀	♀	♂	♂	♂						
5	♂	♂	♂	♂	†	†					
6	*	*	P	♂	♂	♂					
7	♀	†	♀	♂	†	P	†				
8	P	P	P	♂	♂	♂	P				
9	♂	♂	♂	♂	†	†	♂	†	*		
10	*	*	†	♀	♀	♀	P	†	♂		
11	†	*	†	*	†	P	♂	♂	♂	†	♂
12	L	*	*	†	L	L	L				
13	*	*	♂	♂	♀ Cl.	*	*				
14	†	♀	♀	♂	♀ Cl.						

† = larva died during rearing; \* = cell molded or incomplete when nest opened; P = *Melittobia chalybii* Ashm.; L = *leucospis affinis* Say; Cl. = *Coelioxys lucrosa* Cress.

(fireweed and volunteer clovers). Our present knowledge of this species would indicate that it has little value in alfalfa pollination, and attempts to increase its numbers for that purpose probably should not be attempted.

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## A Laboratory Method of Mass Rearing the Black Cutworm, *Agrotis ypsilon* (Rott.), for Insecticide Tests<sup>1</sup>

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A number of techniques have been developed for rearing cutworms of economic importance. Most of those that were developed primarily for life-history studies (Crumb, 1929; Hocking, 1952; King and Atkinson, 1927; Satterthwait, 1933; Snyder, 1954) are unsatisfactory for mass rearing. Mass rearing techniques have been developed for several cutworms of economic importance (Jacobson and Blakeley, 1957; Swingle *et al.*, 1941; Waters, 1937; and Wylie and Palm, 1940). However, the black cutworm, *Agrotis ypsilon* (Rott.), is difficult to rear because of cannibalism.

Since the black cutworm is one of the species of major economic importance in southwestern Ontario, a mass rearing technique capable of yielding 500 to 1000 fourth-instar larvae per week was developed. The availability of laboratory-reared cutworms for bioassay in the laboratory, or artificial infestation of field plots, should make it possible to obtain important toxicological and ecological data. This report describes the rearing technique developed.

### Moths

A stock of pupae capable of supplying 100 moths per week is maintained. Emerging moths are anaesthetized with carbon dioxide, removed, and stored in petri dishes at 35°F. and 70 per cent relative humidity. The moths may be stored under these conditions for at least 14 days without apparent effect on vigour or egg production.

Cages 12 inches by 12 inches by 16 inches high, with sliding glass panels, are provided for maturing and mating the moths. Three sides of the cage are covered to a height of four inches with plastic screen so that the glass panels may be raised to allow air circulation (Fig. 1). Food is provided daily by soaking dental cotton plugs in a 10 per cent dextrose solution and suspending them in the cages on lengths of string. To provide cover and to maintain adequate humidity, folded sheets of paper towelling are moistened and placed in the cages daily.

Twenty moths are placed in each cage. Cages are maintained at  $80 \pm 2^\circ\text{F}$ . for four days. During this period, females develop eggs and mating takes place. As the moths mate only in darkness, the cages are alternated between light in the daytime and total darkness at night. Experiments have indicated that placing more than 24 moths in a cage causes overcrowding, which greatly curtails egg-laying. To provide sufficient eggs to rear 1000 cutworms per week, it is necessary to set up one cage of 20 moths every second day.

After four days, the moths are transferred to gallon glass jars (Fig. 2). A layer of moistened filter paper on the bottom of the jar is provided to maintain humidity. Moistened paper towelling is provided as sites for egg-laying. Food is provided by soaking two or three cotton plugs in a 10 per cent sugar solution and suspending them in the jar with lengths of string. Since the moths lay eggs more freely in the dark, these cages are also alternated between light and dark.

The moths begin to lay eggs four to five days after establishment of the culture. Eggs are laid on string, edges of paper towelling, and the perforated paper covers of the gallon jars. Egg production reaches a peak during the

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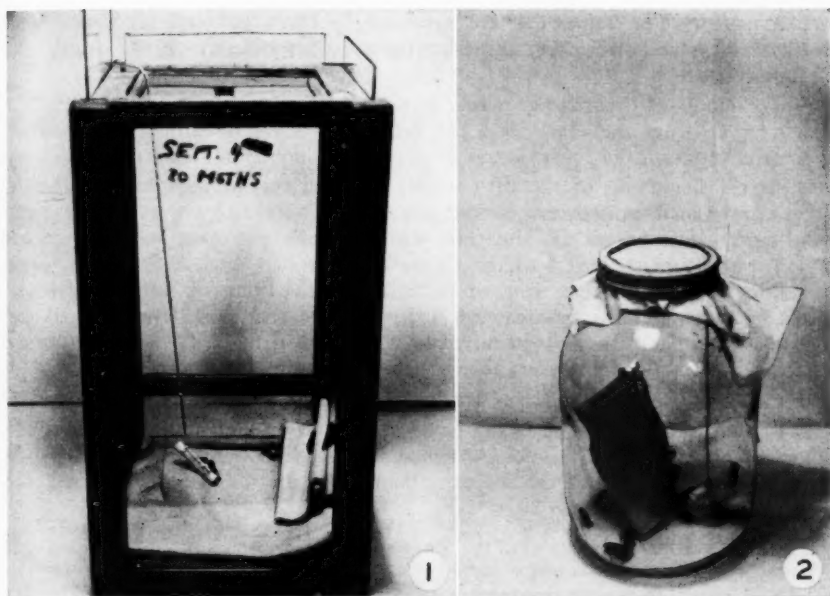


Fig. 1. Cage used for development and mating of moths.

Fig. 2. Cage used for moths during period of egg-laying.

sixth to eighth days, and drops during the following three days. Then the moths are discarded.

#### Eggs

Eggs are collected daily and incubated in petri dishes, 9 centimeters in diameter, for three days at 80°F. No attempt is made to remove eggs from the string or paper towelling since disturbing them causes mortality. Eggs are stored at 35°F. and 70 per cent relative humidity until an adequate number are available for mass rearing. In general, eggs collected over a 5-day period are adequate for rearing 1000 insects. The eggs may be stored at 35°F. and 70 per cent relative humidity for 15 days. Storage for longer periods causes mortality among the eggs and loss of vigour in the larvae that hatch.

Eggs are placed on moistened filter paper in plastic petri dishes 14 centimeters in diameter, and are maintained at 80°F. The eggs hatch within 24 hours. Eggs collected from stock cages over a 5-day period are evenly divided among six petri dishes, red clover being provided for the larvae.

#### Larvae

After three days, the contents of each petri dish are transferred to a pyrex tray, 12 inches by 8 inches by 2 inches deep, containing a 1-inch layer of slightly moistened sand. Fresh clover is added and the trays are covered with glass plates and placed in a rearing room maintained at  $80 \pm 2^\circ\text{F}$ . Development over the next four to five days is rapid, and the majority reach the third instar. The larvae require little attention during the first six days of development.

After seven days, the clover is removed from the trays and thoroughly shaken to remove clinging cutworms. The sand is sifted and sufficient moisture is added to enable the insects to burrow. Larvae then beyond the third instar

are removed. The remainder are returned to trays and fed on clover and tobacco. Early fourth-instar larvae are removed for bioassay on the eighth and ninth days.

To obtain 100 moths per week, it is necessary to rear approximately 200 stock larvae from the ninth day, the remainder being discarded. The larvae are reared through the fourth instar in pyrex trays containing 50 larvae per tray.

At the beginning of the fifth instar, to avoid excessive cannibalism, stock larvae are placed individually in flint jars containing a 1½-inch layer of a 1:1:1 sand-sandy loam-vermiculite mixture with 5 to 7½ per cent moisture added (v/v). Moisture content must be carefully controlled since excessive moisture is conducive to the development of bacterial and virus diseases in the larvae and malformation of moths, whereas too little moisture results in desiccation of the pupae. Prepupae form cells in mixtures with more than five per cent moisture added. The pupal cell appears to prevent desiccation of the pupa.

Fifth- and sixth-instar larvae are fed on Beck's diet (Beck *et al.*, 1949).

Cannibalism and disease in the larval stage, and disease or desiccation in the pupal stage, cause 40 to 50 per cent mortality in the stock culture. Disease is kept to a minimum when the moisture content of the soil is kept low, and the temperature no higher than  $80 \pm 2^\circ\text{F}$ .

#### Pupae

At  $80^\circ\text{F}$ ., the pupal stage lasts 14 days. This period can be reduced to 10 to 12 days by raising the temperature to  $85^\circ\text{F}$ ., but mortality from disease is higher. A temperature of  $80 \pm 2^\circ\text{F}$ . appears optimum for development of both larvae and pupae.

#### Discussion

To date, the cutworm has been reared through 10 generations in the laboratory. The technique is satisfactory for rearing 600 to 1000 insects per week for bioassay. In addition, field plots were artificially infested with laboratory-reared cutworms during the spring of 1957, up to 1200 cutworms being used for a trial.

Rearing through 10 generations on clover, tobacco, and Beck's diet has caused no reduction in the vigour of the culture or in tolerance to insecticides.

Maintenance of a culture yielding 1000 larvae per week requires the services of a technician for three to four hours per day.

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## A Sequential Sampling Technique for Surveys of the Larch Sawfly<sup>1</sup>

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### Introduction

Sequential sampling methods have been developed for population surveys of a number of forest insects (4, 6, 7, 9). These methods permit rapid classification of populations into broad infestation classes with predetermined accuracy and a minimum of sampling, and are useful for mapping and recording widespread infestations.

The method of assessing egg populations of the larch sawfly, *Pristiphora erichsonii* (Htg.), developed by Ives (3) for intensive population studies, was not suitable for surveys because of the large sample size required. A sequential plan for the larch sawfly using hypothetical infestation classes was briefly reviewed by Ives (2). This plan is modified in the present paper in accordance with new data that have accumulated from observations on plots in the White-shell Forest Reserve and other stands in Manitoba and Saskatchewan.

### Considerations Requisite to Sampling

The adult sawflies emerge from cocoons in the ground and lay their eggs in slits cut in the current shoots of tamarack. Oviposition damage to the tissues of the new shoots usually causes them to curl. The degree of curling is apparently related to the extent of shoot elongation at the time of oviposition. If egg laying does not occur until after shoot development is complete, the shoots do not curl and the only signs of damage are the oviposition slits. These, even in uncurled shoots, are easily seen by a careful observer. The average number of eggs per utilized shoot varies between infestations and years, but not sufficiently to affect the broad infestation classes defined for this type of survey. It should therefore be possible to utilize the proportion of shoots that has been used for oviposition to derive an index of population density.

The distribution of shoots utilized for oviposition within various crown levels of the tree was determined by intensive egg sampling (Table 1). The proportion of utilized shoots in the mid-crown was fairly representative of the tree, but there may be considerable variation between crown levels, plots, and years. Composite samples from all crown levels may be statistically superior,

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TABLE 1

The distribution of shoots and proportion utilized for oviposition in each of three crown levels in sample trees. Whiteshell Forest Reserve, Man.

Plot	I	II	I	II	III
Year*	1952	1952	1953	1953	1953
Number of Trees	176	156	2	2	2
Upper crown					
Number of shoots	9055	4511	3967	329	2120
Proportion scarred	.143	.171	.206	.176	.230
Middle crown					
Number of shoots	16184	6193	4703	748	2564
Proportion scarred	.135	.202	.208	.139	.349
Lower crown					
Number of shoots	13563	6355	1390	715	3029
Proportion scarred	.172	.302	.204	.49	.343
Total					
Number of shoots	38802	17059	10060	1792	7713
Proportion scarred	.150	.231	.207	.110	.314
Chi-square	84.4**	301.2**	0.1	44.5**	95.7**

\*The 1953 records are complete tree counts. The 1952 records are two branch samples from each of three crown levels.

\*\*Significant at the .01 level.

but the increased difficulty in obtaining such samples outweighs any possible increase in accuracy. For survey purposes, the mid-crown is considered a suitable sampling universe.

Intensive sampling was also conducted to determine the distribution of utilized shoots within the branch. The foliated portion of each of 48 branches was divided into four equal lengths and the number of utilized and total shoots recorded for each length. The results of this sampling indicate that the proportion of utilized shoots is distributed randomly within branches.

#### Infestation Classes

The relationship between the proportion of utilized shoots and the degree of defoliation was determined by surveys in permanent sample plots. Twenty whole-branch samples were examined in each plot to determine the proportion of shoots that had been utilized for oviposition. After larval feeding was completed, the percentage of defoliation was estimated for each plot and classified as light, moderate, or severe. The infestation classes were then defined as shown in Table 2.

These infestation classes are based on data collected over a wide area in which infestation histories have varied considerably. They should therefore be applicable to conditions usually encountered in the field, although it may be necessary to modify them somewhat to suit local conditions.

#### Sequential Plan

Before a sequential plan can be developed for sampling an insect population, it is necessary to know the underlying frequency distribution. It has been previously shown that the distribution of utilized shoots within the branch is

TABLE 2

Larch sawfly infestation classes based on the proportion of shoots utilized for oviposition and the percentage of defoliation

Infestation class	Proportion of shoots utilized for oviposition	Approximate percentage of defoliation
Light.....	less than 0.08	less than 20
Moderate.....	between 0.12 and 0.22	between 30 and 60
Severe.....	more than 0.28	more than 70

random. During examination, each shoot is classified in one or two categories (egg scars present or egg scars absent). Such data have a binomial frequency distribution. Formulae for the application of the sequential plan using single tests or two tests in parallel for the binomial distribution have been given by a number of authors (5, 8, 9). Armitage (1) outlines a more rigorous simultaneous sequential test for three binomial probabilities. However, he concludes that this test is not very different from the method of two tests in parallel which is used in the following plan.

In sampling larch sawfly egg populations the two errors  $\alpha$  and  $\beta$ , were set at 0.10.

From Table 2 the hypotheses  $H_0$  and  $H_1$  were set up as follows:

Light versus moderate infestations:

$H_0$  — the proportion of utilized shoots is 0.08 or less (light).

$H_1$  — the proportion of utilized shoots is 0.12 or more (moderate).

Moderate versus severe infestations:

$H_0$  — the proportion of utilized shoots is 0.22 or less (moderate).

$H_1$  — the proportion of utilized shoots is 0.28 or more (heavy).

When these values for  $\alpha$ ,  $\beta$ ,  $H_0$  and  $H_1$  are inserted into the formulae for calculating the decision lines for the binomial distribution, the following equations are obtained:

Light versus moderate infestations:

Accept  $H_0$ , if  $d < -4.8854 + 0.0988 n$ ;

Accept  $H_1$ , if  $d > 4.8854 + 0.0988 n$ ;

Moderate versus severe infestations:

Accept  $H_0$ , if  $d < -6.8406 + 0.2492 n$ ;

Accept  $H_1$ , if  $d > 6.8406 + 0.2492 n$ ;

where  $d$  is the cumulative number of shoots utilized for oviposition and  $n$  is the number of shoots examined. These lines are plotted in Fig. 1. Shoots are examined and plotted cumulatively on the chart until the point falls into one of the three zones light, moderate or severe.

The Operating Characteristic (OC) and the Average Sample Number (ASN) curves are not essential in the application of the sequential sampling plan, but are helpful in visualizing the operation of the plan and probable sample size at various population densities. The OC and ASN curves were calculated from the formulae for the binomial distribution and are shown in Figs. 2 and 3 respectively. The OC curves give the probability,  $L(p)$ , of accepting  $H_0$  for different levels of the population mean. For example, if the population mean



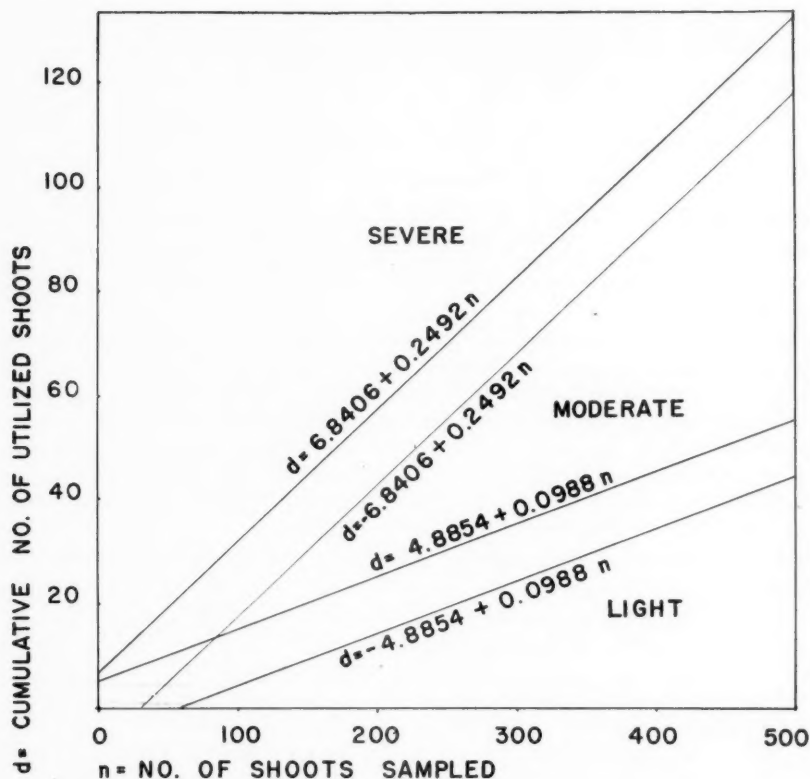


Fig. 1. Sequential graph for sampling larch sawfly populations.

is 0.1, midway between the upper limit for the light infestation class (0.08) and the lower limit for the moderate infestation class (0.12), the probability of accepting  $H_0$  is 0.5. Similarly, if the population mean is 0.12, the probability of accepting  $H_0$  is 0.10. There is practically no overlap between the OC curves for light versus moderate and moderate versus severe, so that the probability of calling a light infestation severe or a severe infestation light is negligible.

The ASN curves are useful in estimating the probable number of shoots that must be examined for different population means before reaching a decision. The average sample sizes are largest if the population mean falls in the zone of indecision between the class limits, i.e. between 0.08 and 0.12, and between 0.22 and 0.28.

#### Application of Plan

The sampling may be conducted any time after the oviposition is completed, usually about mid-August. At each plot trees are selected at random. Using extension pruners, two whole-branch samples are removed from the mid-crown of the sample trees. The current shoots on each branch are examined in groups of 10 from the tip of the branch toward the base. When the number of shoots on the branch is not a multiple of 10 the remaining shoots are carried over to the

next branch. This grouping of the shoots does not alter the properties of the plan, except possibly to increase the sample size slightly, and greatly facilitates its application in the field. Following examination of each group of 10 shoots, the cumulative number of shoots that have been utilized for oviposition are re-

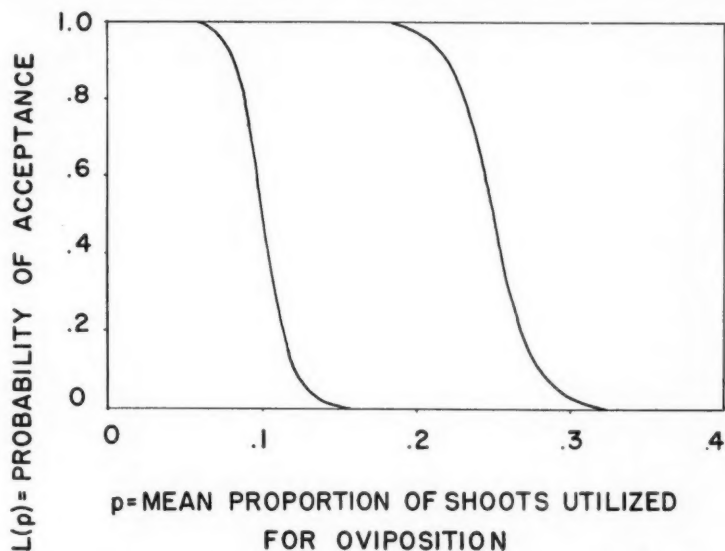


Fig. 2. Operating Characteristic Curve for the sequential plan of sampling larch sawfly populations.

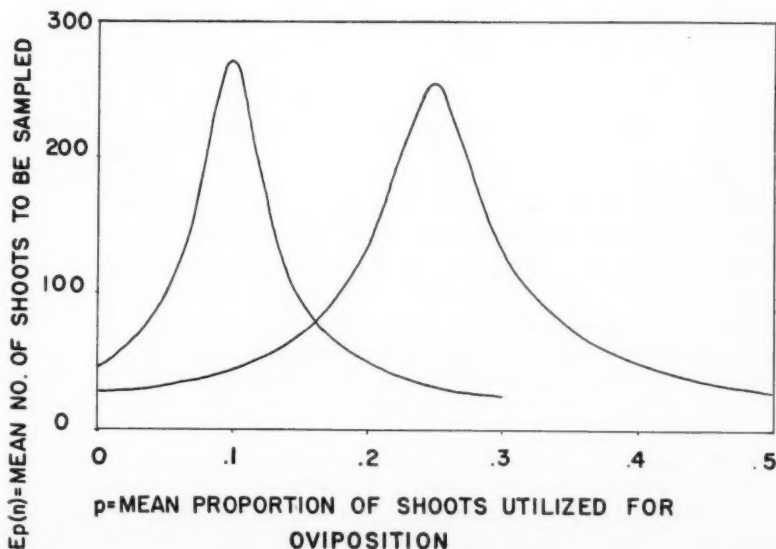


Fig. 3. Average Sample Number curves for the sequential plan of sampling larch sawfly populations.

TABLE 3

Sequential table for use by field parties in classifying infestations. Sampling continues until the cumulative number of shoots utilized for oviposition falls outside of either of the two bands into one of the three zones.

No. of shoots examined	Cumulative No. of shoots utilized for oviposition			
	Light-moderate band		Moderate-severe band	
10	LIGHT ZONE	-	MODERATE ZONE	- 9
20		-		-11
30		-		-14
40		-		-16
50		1-		-19
60		2-		-21
70		3-		-24
80		4-12		14-26
90		5-13		16-29
100		5-14		19-31
110		6-15		21-34
120		7-16		24-36
130		8-17		26-39
140		9-18		29-41
150		10-19		31-44
160		11-20		34-46
170		12-21		36-49
180		13-22		39-51
190		14-23		41-54
200		15-24		43-56
210		16-25		46-59
220		17-26		48-61
230		18-27		51-64
240		19-28		53-66
250		20-29		56-69
260		21-30		58-71
270		22-31		61-74
280		23-32		63-76
290		24-33		66-79
300		25-34		69-81
310		26-35		71-84
320		27-36		73-86
330		28-37		76-89
340		29-38		78-91
350		30-39		81-94
360		31-40		83-96
370		32-41		86-99
380		33-42		89-101
390		34-43		91-104
400		35-44		93-106
				SEVERE ZONE

corded. This may be done either on the graph as shown in Fig. 2 or in tabular form as shown in Table 3. The latter is more suitable for field use. When necessary, additional two-branch samples are taken and counts of shoots, in groups of 10, continue until the cumulative number of utilized shoots fall outside of one of the bands into one of the three zones. As shown by the ASN curves in Fig. 3 it is unlikely that more than 400 shoots will be examined in reaching a decision. However, should no decision be reached after sampling this number of shoots a truncation procedure as suggested by Wald (8) may be adopted. With  $d$  in the light-moderate band, the infestation is classed as light, if  $d < 39$ , and moderate if  $d > 40$ . Should  $d$  be in the moderate-severe band, the infestation is classed as moderate if  $d < 99$  and heavy if  $d > 100$ .

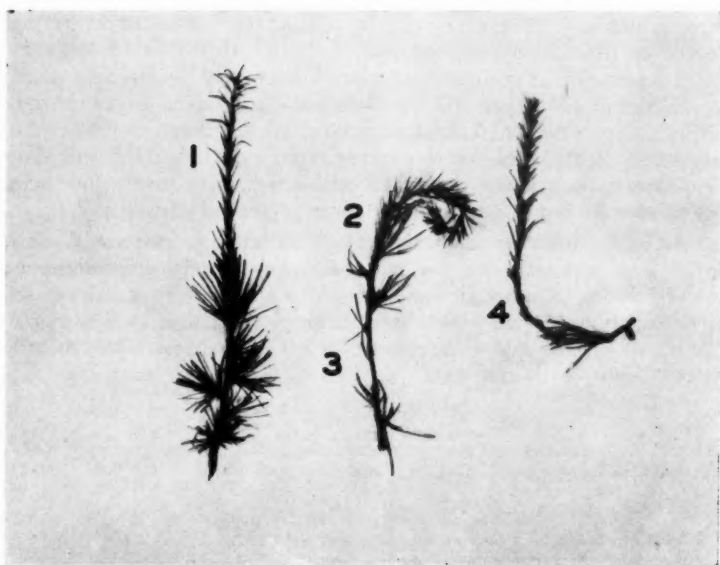


Fig. 4. Illustration of tamarack shoots.

1. Current normal shoot
2. Current shoot utilized for oviposition
3. Old normal shoot
4. Old shoot utilized for oviposition

Two hypothetical examples of the sampling procedure are shown below for illustrative purposes. If counts of 1, 0, 0, 1, 0, 0, and 0 utilized shoots were recorded on successive groups of 10 shoots, sampling would cease after the last group (7th) and the infestation would be classed as light. Similarly, if counts of 2, 1, 0, 3, 3, 1, 0, 2, 0, and 3 utilized shoots were recorded on successive groups, sampling would cease after the last group (10th) and the infestation would be classed as moderate.

In the fall of 1956, infestations in 48 permanent tamarack sample plots were classified by sequential sampling. Infestations fell into the light and moderate classes, no severe infestations being encountered. The sequential sampling ratings and the defoliation ratings agreed in all but two plots. The sampling time for classifying infestations in various plots ranged from one to three hours.

#### Discussion

It is important that only current shoots be examined in the application of the sequential sampling plan. These may be distinguished from old shoots by their lighter coloration and by the absence of conspicuous fascicle bases, also the needles on new shoots are produced singly, whereas the needles on old shoots are produced in fascicles. Some of the types of shoots encountered in sampling are shown in Fig. 4.

A number of factors may affect the limits of the infestation classes defined for sequential sampling in Table 2. Host tree reactions to defoliation are usually reflected in changes in shoot and foliage production. The rates of decline in foliage and shoot production on tamarack after severe attack are not completely

understood, but any changes in one in relation to the other would influence the degree of defoliation resulting from a fixed proportion of utilized shoots. During the course of an outbreak shoot production may decline to a point where a high utilization of shoots will produce sufficient larvae to cause only light defoliation. Alternatively, if foliage production decreases in relation to shoot production, or if the trees are recovering from a severe attack and shoot production increases in relation to foliage production, a relatively low proportion of utilized shoots may be sufficient to cause severe defoliation.

It may be necessary to adjust the infestation limits for sequential sampling in local areas to compensate for any marked changes in the relationship between shoots and foliage. Annual records on shoot production in permanent tamarack plots are maintained by the Forest Insect Survey. Changes in shoot production should help to explain any discrepancies which may appear between infestation ratings and subsequent defoliation.

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## Observations on the Flight, Wing Movements and Wing Structure of Male *Priacma serrata* (Lec.) (Coleoptera: Cupedidae)<sup>1</sup>

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### Introduction

During May, 1957 near Lumby, B.C., there was a reoccurrence of the gregarious flight behaviour of *Priacma serrata* males observed the preceding year (Atkins, 1957). Once more these beetles exhibited a strong attraction to "Perfex" laundry bleach, which is an aqueous solution containing 5-5.5 per cent sodium hypochlorite and 4.3 per cent sodium chlorate. They swarmed around the bleach-treated articles every fair day from the 5th of May until the first week of June. This situation presented an ideal opportunity to study certain aspects of the behaviour of this strange insect and accordingly observations were made on the beetles' flight both in the field and under laboratory conditions.

### General Observations

Starting on May 1, towels dipped in a solution of bleach were hung out in the area of the 1956 "swarming". The first few *Priacma* appeared mid-morning of May 5, when the air temperature was 60°F. They fluttered around and, at intervals, settled on the towels until late afternoon. Snow was still on the ground in well shaded places. The beetle reappeared in increased numbers about 9:00 a.m. on May 6, and appeared on each of the next six days, disappearing with the onset of heavy cloud and rain on May 12. As the presence of *Priacma* was noted for only four days in 1956, I felt that the flight was over for the year. However, more beetle appeared during the warmer hours of the following unsettled days. They continued to visit the bleach-treated articles until June 4. Collections and observations were made throughout this period.

The attraction to the bleach was very pronounced and constantly demonstrated by the beetle flying out of the woods and settling on the treated towels. Once in the vicinity of the bleach, they fluttered around and walked on the towels and adjacent trees. As many as 56 *Priacma* males were counted on a hand towel at one time. Bleach-treated towels were taken to three nearby locations in an opening in the forest (a mixed stand of Douglas fir, western red cedar, western hemlock, lodgepole and white pines and larch) where these insects had not previously been seen; within five minutes, dozens of cupedids were flying around. The previously reported copulatory posture (Atkins, 1957) was always noted in the vicinity of the bleach.

The flight of the bleach-stimulated beetles was characteristic and differed considerably from that of individuals remote from the stimulant. When a number of *Priacma* males were "swarming" around the bleach they fluttered close to the towels, landing frequently, walking around erratically, then flying again. Their flight was weak and a slight breeze easily reversed their direction. When the air was calm they hovered and in some cases appeared to move backwards. Many of them collided with obstacles in their path and fell to the ground, unable to maintain their flight. They flew only short distances at one time, landing, crawling to a suitable take-off spot, then flying again.

On the other hand, when the beetles were released individually in a room or in an opening in the forest, their flight was strong and directed. In a wind-free room they flew directly towards the window. When released outdoors they flew at 90° to the sun in calm air or with the wind when it was present (see also Lutz, 1927 and Johnson, 1950). They flew from the starting point

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to a height of 25 to 50 feet and then in a straight line, deviating only to avoid obstacles. Several individuals were followed to the timber margin 200 yards from the release point, where they disappeared from sight over the trees.

During both types of flight, the flight attitude of the beetles was the same. The antennae were pointed forward as were the front legs. The femora of the mesothoracic legs were held up against the side of the body while the tibial and tarsal portions were directly slightly forward. The metathoracic legs were directed backwards and spread lightly away from the body. The thoracic region was gently humped and the abdomen was upcurved. Sometimes the terminalia were extended but usually remained in repose (see Fig. 1a). Body and wing proportions are shown in Fig. 1b.

#### Flight Preparation and Response

Before flight, the *Priacma* males went through a definite pattern of movements. In a wind-free room they walked towards the light and climbed to the highest point on nearby objects. Outside, the beetles walked down wind and if the sun was shining they flew almost immediately. Unless "swarming" or stimulated by tossing, these insects would not fly in the shade or during cloud at temperatures below 70°F.

Just before taking flight the beetles raised their antennae and waved them in all directions. The very movable head and prothorax were raised and moved from side to side. The front legs were arched, raising the head and prothorax, while the other legs were spread and planted firmly on the substrate. The tip of the abdomen was pressed downward. The elytra were then spread slightly and the wings and elytra were flicked spasmodically several times. An attempt to fly invariably followed this procedure but was often unsuccessful; the beetles would either fall on their backs or flutter only a few inches. The spasmodic flicking of the wings and elytra and the pressing down of the abdomen often preceded flight when the beetles were suspended by the prothorax on fixed mounts.

As with many other insects (Roeder, 1953) a strong stimulus to flight can be given to *Priacma* males by removing the tarsal contact. When tossed into the air the beetles would nearly always fly or spread their wings and elytra. Usually several tosses were required before the beetles flew successfully. Direct sunlight also appeared to be a strong flight stimulus to *Priacma*. When the air temperature was below 70°F. or when they would not fly on flight mills, they could be stimulated to fly by placing them in direct sunlight. This behaviour resembles that of the Douglas-fir beetle, *Dendroctonus pseudotsugae* Hopk.; Rudinsky and Vite (1957) found that this beetle would not taken flight at temperatures below 68° F., unless stimulated by radiant heat.

#### Flight Duration

This phase of the beetles' flight was studied on a flight mill as modified from Hocking (1953). The beetles were attached by wax to small points of aluminum foil which in turn were fastened to capillary tubing arms rotated on the points of insect pins.

A total of 40 beetles were attached to the mill for 4-hour intervals, but all reached a stage of complete fatigue long before this time had elapsed. The longest continuous flight recorded was 23 minutes. The average duration of the first flight was 11 minutes. After terminating the first flight the beetles usually remained flightless for several minutes, then flew again. Some individuals exhibited a start-stop behaviour, never flying more than three or four minutes at one time.

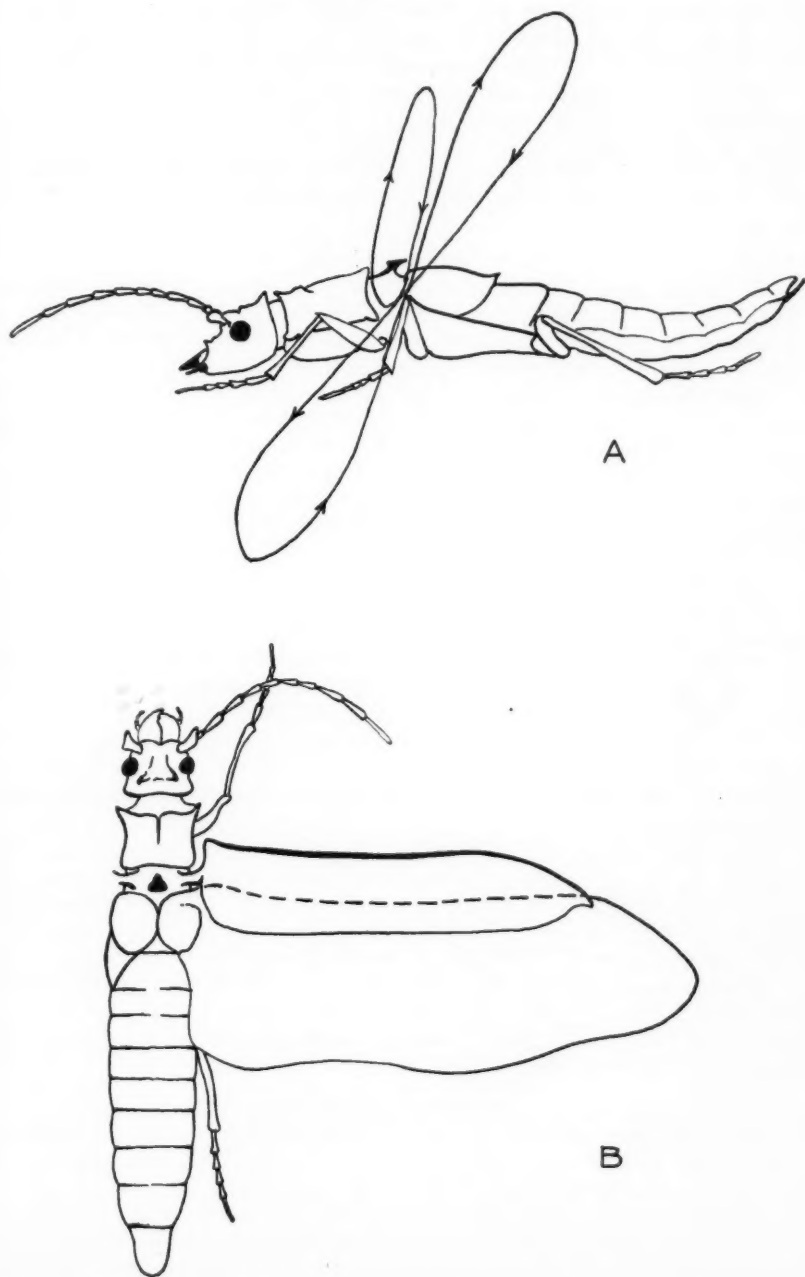


Fig. 1 (a) Flight posture of *Priacma serrata* male flying on a fixed mount. Path of wings and elytra shown by arrows.

(b) Dorsal view of *Priacma serrata* male showing body and wing proportions.

The longest total flying time for one beetle during the 4-hour period was 38 minutes. The average total flying time was 16 minutes, while the longest time elapsing before a beetle ceased flight attempts was 60 minutes.

One series of cupedids was placed on flight mills while the temperature of the laboratory was rising from 80° to 102° F. Four of the beetles made short flights of 2-3 minutes, but as the temperature reached 102° F., neither the original beetles nor individuals brought in from outside made any attempt to fly. A small buprestid, *Melanophila Drummondi*, flew continuously through the test.

#### Flight Velocity

*On Flight Mills.*—The value for the flight velocity obtained from flight mills varies with the length of the rotating arm and with the flight position of the beetle. Higher speeds were obtained when the insect was nearly horizontal (see also Hollick, 1940), or when the mill arm was shortened.

Beetles placed at a similar angle on mills describing a circumference of one metre had velocities ranging from 42 to 106 metres per minute. The most common velocities during the first five minutes of flight were from 60 to 76 metres per minute or 2.2 to 2.8 miles per hour. The velocity became reduced after the first few minutes of flight and constantly diminished until flight was terminated. This is believed to have been due to changes in wing-stroke amplitude, discussed later.

*In a Wind Free Room.*—To prevent the initial velocity, which is lower due to the inclination of the insect's body, from affecting the steady flight velocity, the beetles were tossed at one end of the room and allowed to fly for several feet before being timed. The beetles were clocked with a stop-watch from the time they passed a point in level flight until they reached a window three metres away.

The velocities varied considerably according to the flight path of the beetle. Those which flew nearly straight and level, had velocities of between 72 and 90 metres per minute. This was considered the normal velocity under these conditions.

*Outdoors.*—The value for the free flight velocity outdoors was obtained by releasing beetles and timing their flight to various objects. They invariably flew upward from the release point so their estimated height was considered when determining the flight distance. Speeds were corrected for wind velocity at the time. The results of releasing 15 beetles are presented in Table I.

The most common flight velocities on the mills were from 10 to 20 metres per minute less than the free flight velocity in a wind-free room or outdoors. The normal free flight velocity probably lies in the vicinity of 80 metres per minute or 3 miles per hour.

#### Wing-Beat Amplitude

The wing-beat amplitude was measured by viewing flying insects from the front through a circular aperture in a white card and visually lining up the leading edges of the wings with a straight edge.

During flight on a fixed mount each wing tip initially describes an arc of 155°, while the broader anal portions travel farther due to wing deflection. At the top of the stroke the tips come to within 5° of the vertical; the anal portions touch at this point as the wings rotate on their long axis. At the bottom of the stroke the tips come to within 20° and the anal portions to within 5° of the vertical, as the wings rotate.

TABLE I  
Flight Velocities Resulting From the Release of 15 *Priacma serrata* Males Outdoors

No.	Flying time (seconds)	Horizontal distance (metres)	Height (metres)	Flight <sup>1</sup> distance (metres)	Air speed of beetle (metres/min) <sup>2</sup>
1	5	8	3	8.5	72
2	4	8	3	8.5	97
3	7	9	8	12.0	73
4	7	9	5	10.5	60
5	7	10	4	11.0	64
6	5	8	5	9.5	84
7	7	14	6	15.0	99
8	7	14	5	15.0	99
9	6	9	6	11.0	80
10	7	12	6	13.5	86
11	5	9	4	10.0	90
12	5	8	5	9.5	84
13	7	14	7	15.5	103
14	7	11	6	12.5	78
15	6	10	5	11.0	83

<sup>1</sup>To nearest .5 metres.

<sup>2</sup>Air speed takes into account a wind velocity of +30 metres/min.

The tip of each elytron at first describes an arc of  $45^\circ$  from the horizontal, a movement which is considerably more than is reported for the wing cover of beetles (Pringle, 1950). This may be related to the primitive nature of the insect (Böving and Craighead, 1930).

During fixed flight the wing-stroke amplitude changed soon after the beetle had begun to fly. The amplitude was gradually reduced at both the top and the bottom of the beat. Hollick (1940) found that the wing stroke amplitude of *Muscina stabulans* changed only at the bottom of the beat. As *Priacma* flew, the beat amplitude decreased until in most cases the activity of the wings was reduced to the lower half of the stroke. Sometimes the wings remained vibrating at the bottom of the stroke for several minutes. The amplitude of the elytra changed very little and in the case of two beetles with suspended wing movements, the beating of the elytra produced sufficient propulsive force to move the mill arm. This raises a question as to the importance of the elytra in the flight of beetles (see Demoll, 1918; Pringle, 1950).

A series of photographs taken with a flash (.001 sec.) almost stopped the wing movements. In every picture the positions of the wings and elytra are opposite to each other. When the wings were at the bottom of their stroke, the elytra were at the top of their stroke. This results in a counter-propulsion system as found in the dragon flies (Curran, 1948). Investigations may show that such a system of wing movement in insects, in which the fore- and hind-wings are not fastened together, is more common than presently recognized.

As the wing-beat amplitude became reduced, the flight velocity was also reduced. Hollick (1940) found that the wing-beat amplitude of *Muscina stabulans* was reduced with increased forward speed. The changes in amplitude in *Priacma* males occurred even when they were flying on a stationary mount and appeared to be a normal course of events regardless of forward movement. This gradual reduction in amplitude and corresponding reduction in flight velocity is probably the result of muscular fatigue. The changes in amplitude

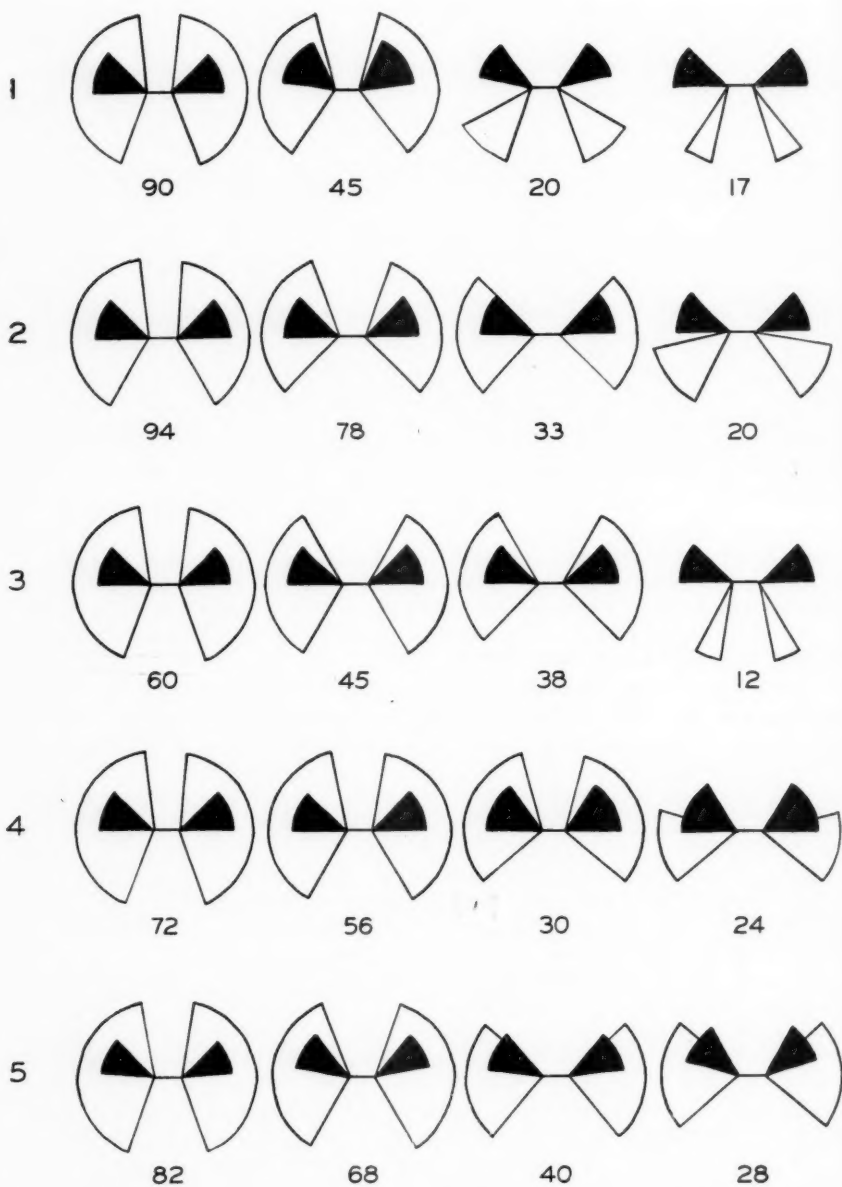


Fig. 2. Frontal view of changes in wing and elytra amplitudes of 5 *Priacma serrata* males. The numbers under each diagram indicate the flight velocity on a flight mill in metres per min.



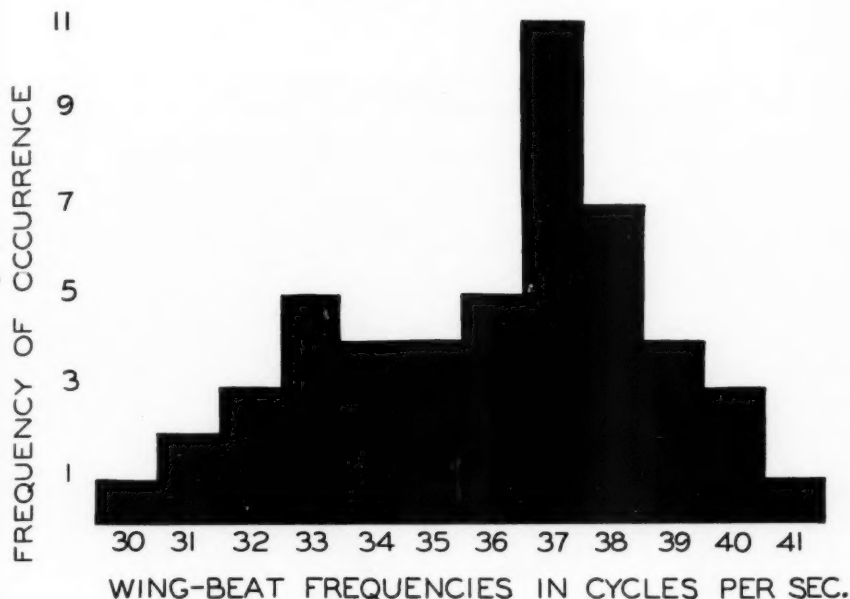


Fig. 3. Wing beat frequencies of 50 *Priacma serrata* males.

and the corresponding flight velocities taken every three minutes for five individuals are shown in Fig. 2.

#### Wing-Beat Frequency

The stroboscope method of studying wing-beat frequency (Chadwick, 1939) was used. The stroboscope was calibrated against an audio generator (by an oscilloscope screen) which was checked at the 60 cycle point with line frequency. The overall accuracy of the wing-beat determination was certainly within  $\pm 5$  per cent. The beetles were mounted as previously noted and then held near the flashing tube of the stroboscope.

Fifty *Priacma* males tested had wing-beat frequencies ranging from 30 to 40 cycles per second. The mean frequency for the group was 36 cycles per second. (Figure 3 shows the distribution of wing-stroke frequencies.)

By adjusting the stroboscope to one or two cycles per second off the wing-beat frequencies of the beetles the secondary wing movements could be observed easily. When flying on a fixed mount the figure eight pattern of wing deflection of *Priacma* was the reverse of the pattern usually described for insects. On the down-stroke the hind margins were depressed, making the area of increased pressure in front of the wings. On the up-stroke the anterior margins were depressed. The reason for this is not understood, but stationary flight may be similar to hovering flight. If so, this pattern of deflection, moving the resultant force backwards, might arise from the lack of any stimulation produced by forward movement.

#### Wing Folding and Venation

The width of the wings of *Priacma* males is reduced by longitudinal folding along four main lines. The length is reduced by retraction of the tip

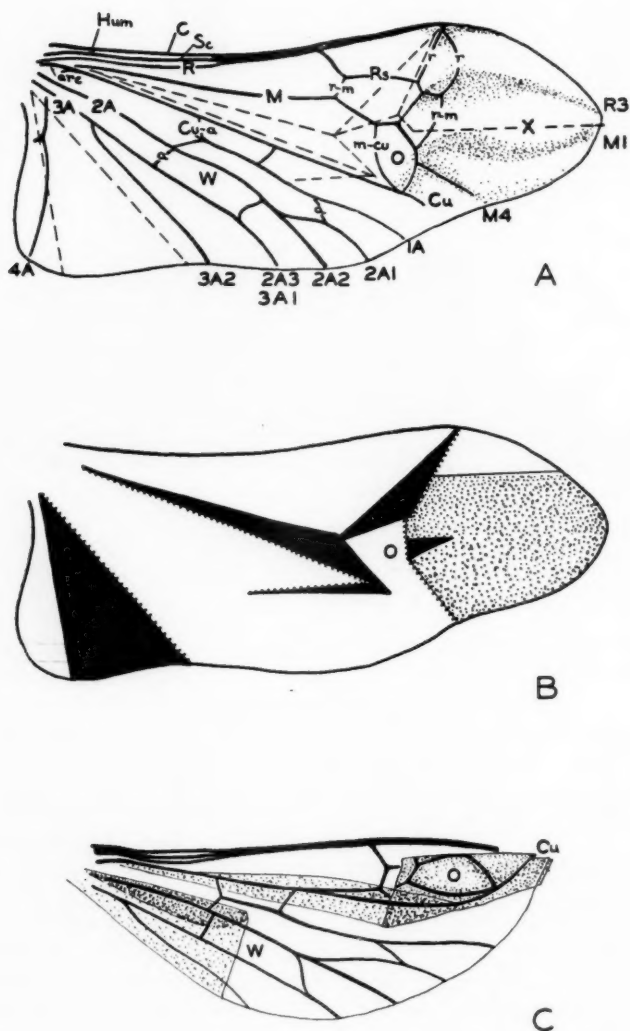


Fig. 4 (a) Right wing of *Priacma serrata* male showing venation and fold lines (broken).  
 (b) Right wing of *Priacma serrata* male showing pattern of folding. Black indicates areas of wing reversed. White indicates areas normal or following two consecutive folds. Stippling indicates rolled area. Smooth lines denote concave folds. Serrated lines denote convex folds.  
 (c) Folded right wing of *Priacma serrata* male. A — anal, a — anal, arc — arculus, C — costa, Cu — cubitus, Cu-a — cubital anal, Hum — humeral, M — media, M-cu — medio-cubital, O — oblengum cell, R — radius, Rs — radial sector, r — radia, r-m — radio-medial, Sc — subcosta, W — wedge cell.

brought about by folding along four transverse lines. The apical area is supported by three callosities derived from veins  $R_s$ ,  $M$ , and  $M_1$ , and is spirally rolled in repose around a central longitudinal axis marked X on Fig. 4a. In contrast with many beetles the wings of this species remain folded when detached from the body. If a wing is unfolded it will spring back to the folded position initially brought about by the rolling of the tip. When the wings are folded beneath the elytra the anal areas overlap while the remaining anterior portions lie almost dorso-ventrally. The fold lines are shown in Fig. 4a. A diagram of wing folding is shown in Fig. 4b, and a folded wing is shown in Fig. 4c.

The venation of the wings of *Priacma* males is more complex than of other cupedid wings previously described (see Forbes, 1922), there being more cross veins and six enclosed cells. The venation shown in Fig. 4a is named according to the theory that the cubitus is a single vein in beetles, the second cubitus being replaced by the first anal, thus producing an anal fan made up of four main veins.

#### Acknowledgments

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## The Pine Weevil, *Pissodes approximatus* Hopk., in Southern Ontario<sup>1</sup>

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### Introduction

In recent years there have been marked increases in populations of a pine weevil, *Pissodes approximatus* Hopk., in southern Ontario, especially in areas where pine trees, particularly Scots pine, *Pinus sylvestris* L., are grown in pure stands for the Christmas tree market. In several such areas where large weevil populations have built up in the stumps of the previous year's cutting, damage to remaining trees by adults feeding on the twigs and small branches has been heavy. Not only has the quality and value of the trees been reduced by this damage, but in some instances the trees have been killed (5).

*P. approximatus* is native to North America. It was described in 1911 by Hopkins (8), who reported the following pines as hosts: *Pinus strobus* L., *P. rigida* Mill., *P. banksiana* Lamb., *P. echinata* Mill., *P. resinosa* Ait., *P. virginiana* Mill., and *P. pungens* Lamb. He recorded its distribution as Wisconsin, Michigan, Pennsylvania, New York, New Hampshire, Massachusetts, Virginia, West Virginia, and North Carolina in the United States, and southern Ontario in Canada. He stated that it bred in the thick bark of the tree, sometimes causing serious damage to the sapling stage. Since 1911, *P. approximatus* has also been recorded in Connecticut (2) and in Ohio (3). In 1929, Böving (1) discussed the taxonomic differences between the mature larvae of *P. approximatus* and the white pine weevil, *P. strobi* (Peck). Plummer and Pillsbury (9) reported that although the breeding habits of the two weevils differed, their seasonal histories were very similar, and suggested that they might prove to be one species since they had been successful in rearing *P. strobi* experimentally in the trunks of weakened trees. That they are indeed different species is shown by the difference in their chromosome numbers (S. G. Smith, unpub.) and the absence from *P. strobi* of the chromosomal polymorphism reported in *P. approximatus* (11). The importance of *P. approximatus* as a secondary pest in areas where pines have been weakened by defoliators, *Ips* bark beetles, or by transplanting, has been pointed out by Easterling (3), Felt (4), and Shaffner (10).

There is at present only scant information available on the bionomics of this weevil and its present status in the northeastern United States is not clear, although Holt (7) has reported that it is becoming an increasingly serious pest in coniferous plantations in Pennsylvania.

### Methods

The investigations of *P. approximatus* were carried out in Simcoe County in southern Ontario, during the 1955 and 1956 growing seasons. Field observations were made in several widely separated plantations of red pine and Scots pine, and in nursery seedling beds; the laboratory observations were conducted at a field station at Angus, Ont.

The seasonal history and habits of the weevil were determined by setting up trap logs in the field at weekly intervals throughout the growing season. When the immature forms had reached the pupal stage, the infested logs were transferred to outdoor cages, where the insects were reared through to adults. Each set of trap logs was sampled weekly, and the development of the im-

<sup>1</sup>Contribution No. 442, Forest Biology Division, Science Service, Department of Agriculture, Ottawa, Canada. Based on part of a thesis to be submitted as partial fulfilment for the degree of Doctor of Philosophy at the University of British Columbia.

mature stages in them was checked. Observations were also made at weekly intervals on natural weevil populations in pine stumps in the field.

A special technique was devised for rearing the weevil in the laboratory. This consisted of rearing the insect from the egg to the adult stage under glass, on fresh inner bark of Scots pine removed from the tree. The newly hatched larvae were placed in small grooves made on the cambial surface of the bark which was then pressed tightly against the bottom of a petri dish by filling the dish with sand and applying pressure on the cover with rubber bands. This rearing method permitted continuous observation of larval and pupal development, and the periodic measurement of body size and extent of larval feeding. It was possible to keep the inner bark green and free from fungus contamination for more than two weeks by using sterilized sand and glassware, and by keeping to a minimum the time that the cambial surface of the inner bark was exposed to the air during preparation. During rearings some larvae were transferred to fresh bark after each moult while others were transferred after two moults, thus permitting more accurate measurements of the feeding damage by each instar. After the fourth-instar larvae had constructed pupal chambers, they were left undisturbed until the adults were formed.

Forty-two weevils were reared in this manner from egg to adult during the summer of 1956. The larvae thrived on the inner bark and their development corresponded very closely to that of free populations in the field.

#### Description of Life History Stages

##### Adult

The adult *P. approximatus* is a typical curculionid and closely resembles the white pine weevil, *P. strobi*. It varies considerably in size, being from 5 to 8 mm. in length and from 2 to 3 mm. in width. The females are, on the average, 1 mm. longer than the males. The newly emerged adult is medium brown, darkening to almost black after having overwintered. The prothorax, elytra, and legs are marked with tufts of white and reddish-brown scales grouped to form several small spots on the prothorax and usually two irregular bands across the elytra. The curved snout is slender and about as long as the prothorax, with the antennae attached about midway along its length. Hopkins (8) separates *P. approximatus* from *P. strobi* by the "average large size, elongate body, the sides of the elytra more distinctly narrowed posteriorly. The beak is longer, and the spots of the elytra are uniformly smaller, the posterior ones rarely connected".

##### Egg

The egg is ovoid and measures from 0.7 mm. to 0.9 mm. in length and 0.4 mm. to 0.6 mm. in width. When first laid it is almost colourless with a smooth glistening chorion.

##### Larva

The larva is typically curculionid in form. When fully grown it is about 12 mm. in length with a light brown head and a white body. The adults reared in the insectary from eggs all passed through four larval instars. Fig. 1 illustrates the distribution of measurements of head-capsule width of reared larvae as they developed through each instar from the egg to the pupal stage. A field check was made on the last instar by measuring the head capsules of 112 pre-pupae collected in the field from chip cocoons. The cross-hatched polygon in Fig. 1 represents these measurements and indicates good agreement with measurements of the reared material. Table I shows a comparison between the observed head capsule widths and those estimated using Dyar's rule and on

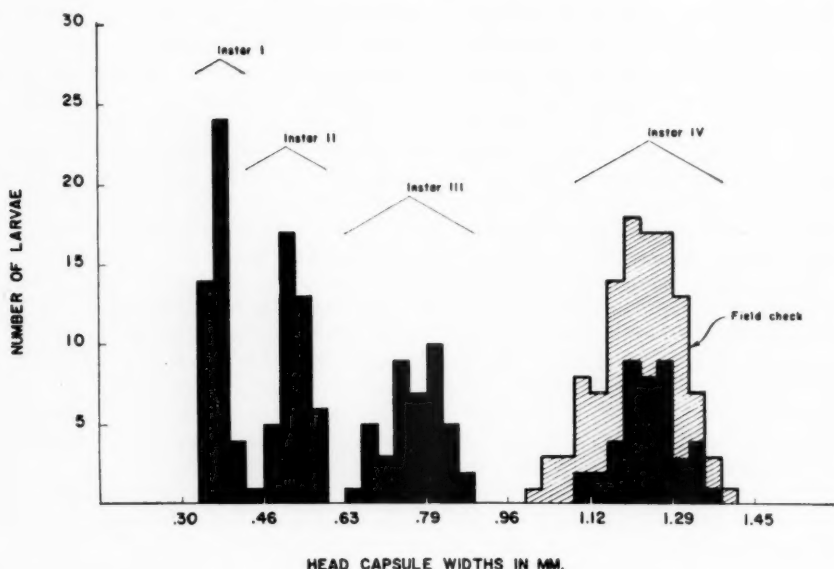


Fig. 1. Distribution of head-capsule measurements of *Pissodes approximatus* larvae.

the basis of a linear regression relationship. It is evident that the increase in width from one instar to the next follows Dyar's rule more closely than the linear regression suggested by Ghent (6) for certain sawflies.

#### Pupa

The pupa is completely white when first formed, but the mandibles, eyes, rostrum, prothorax, and legs become medium brown before adult emergence.

#### Seasonal History and Habits

In southern Ontario, *P. approximatus* overwinters in the larval, pupal, and adult stages. This, together with the fact that there is a long oviposition period, leads to a complicated seasonal history with generations of both one and two

TABLE I

Comparison between observed head-capsule widths and those estimated by using Dyar's rule and on the basis of a linear regression relationship

Instar	Observed width	Dyars' rule		Linear regression	
		Calculated width	Per cent error	Calculated width	Per cent error
I	.354	—	—	.285	+19.5
II	.512	.534	-4.3	.568	-10.9
III	.755	.805	-6.6	.852	-12.9
IV	1.218	1.215	+0.2	1.135	+6.8



years' duration (Fig. 2). Most of the insects overwinter in the adult stage in the duff and top soil overlying the roots and under scales and in crevices of the rough outer bark of pine trees. The remainder overwinter in the larval and pupal stages in the tree, emerge as adults in late June and July of the following year, and overwinter once again. The overwintering adult population thus consists of the progeny of the previous winter's overwintering adults, plus adults developed during the previous summer from overwintered larvae and pupae. In the spring, overwintered adults from these two sources are indistinguishable.

The overwintered adults emerge in early May and feed for about three weeks on the inner bark of pine branches and on the stems of seedlings and small trees. The underside of low-lying branches in contact with the litter are particularly attractive to feeding adults. Fresh feeding wounds made by this weevil are somewhat different from those made by *Hylobius pales* (Hbst.) and *H. radialis* Buch., two other weevils that may feed on young pines in association with *P. approximatus*. Whereas the *Hylobius* adults chew irregular pits in both the outer and inner bark, *P. approximatus* leaves the outer bark intact except for small punctures through which it inserts its beak and chews out larger areas of the inner bark. This makes the feeding damage of *P. approximatus* less noticeable, especially when it is fresh. When the bark on the injured twigs become weathered, however, the outer bark flakes off and the feeding damage resembles that of *H. pales* and *H. radialis*. In areas where large *P. approximatus* populations exist, feeding damage on healthy pines is usually very heavy. In 1956, a Scots pine plantation near Paris, Ont., suffered over 5 per cent mortality in the second year of attack (5).

During the last half of May, there is a mass flight period when the weevils search for suitable breeding material. Mating takes place at this time and oviposition begins about late May.

The first egg was found in the field during 1956 growing season on May 26, while in the laboratory the first egg was laid on June 13. Most of the females lay their quota of eggs before the end of the first week of July and then die. The adult population in the field, therefore, declines rapidly early in July, but a few females continue laying until early September (Fig. 2).

The weevil normally breeds in the inner bark of decadent or dying pines. The whole tree may be attacked from the roots up to branches as small as one-half inch in diameter. Recently transplanted trees are particularly attractive to the weevils. Of forty 9-year-old Scots pines transplanted in October, 1955, from the Provincial Nursery at Midhurst to a heavily infested area near Angus, Ont., five were attacked by large numbers of weevils in June, 1956, and died before the end of July of the same year. A count made of the larval population in these trees revealed an average of 224 larvae per square foot of bark in the lowest 2 feet of the trunk.

Trees of all age classes from 1- and 2-year-old seedlings to mature trees may be attacked. In seedlings, where the bark is too thin to accommodate mature larvae, the larvae bore to the centre of the stem, where they pupate. This type of damage was particularly noticeable in seedlings of Austrian pine, *Pinus nigra* Arnold, in the Midhurst nursery, where about 9 per cent were killed by the weevil in 1956.

The eggs may be laid throughout the trunk and large branches, but the rougher bark at the branch nodes seems to be preferred. In the insectary, nine females laid an average of 47 eggs each, with one laying 62. The eggs are

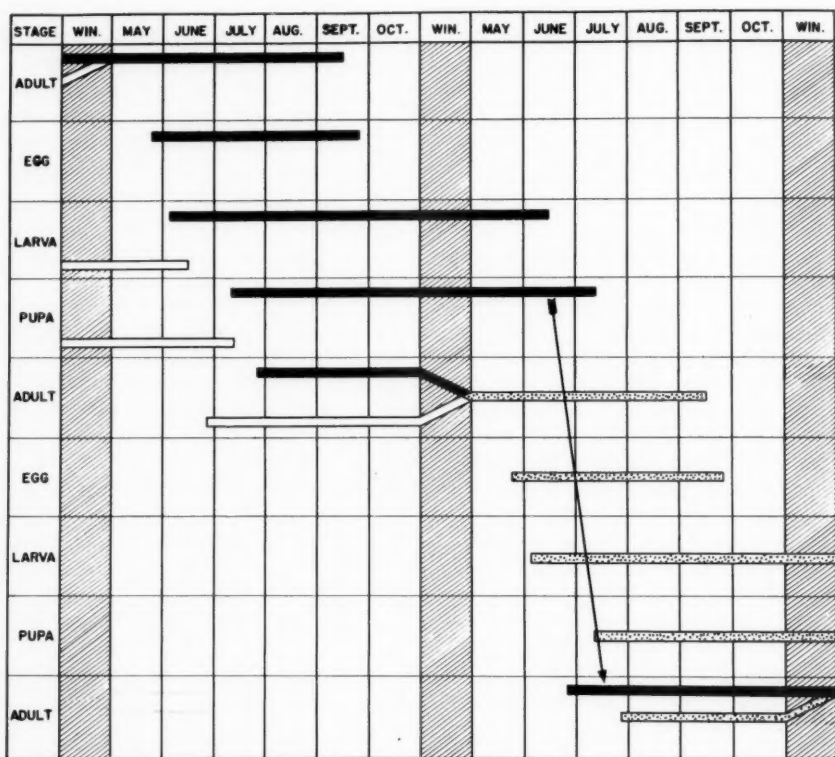


Fig. 2. Seasonal history of *Pissodes approximatus* in southern Ontario.

deposited in pockets chewed in the inner bark by the females. They are normally laid individually in the pockets, but frequently groups of four or five eggs may be found together. Of 521 eggs laid in the laboratory, only 11 (2.1 per cent) did not hatch. The incubation period is about eight days.

The newly hatched larvae are very small, measuring about 1 mm. in length. Immediately upon hatching they begin feeding in the cambial layer. They normally mine in either direction along the grain of the wood unless interrupted by obstacles, in which case they either change direction through 180° or work around the obstacle and continue with the grain of the wood.

Larval development requires about 36 days. Table II shows the average duration of each of the four instars and the average length of the mines excavated by each.

When the larvae attain maturity, they construct "chip cocoons" typical of the genus *Pissodes* in the outer surface of the wood. Pupal development takes place in these chambers and requires three or four days. The pupal period lasts about two weeks. The developmental period of 42 weevils reared from egg to adult in 1956, was  $59.8 \pm 10.2$  days.

Newly formed adults remain in the pupal chamber about five days before chewing their way to the outside, when the cuticle soon hardens and darkens

TABLE II  
The duration of the immature stages and the damage caused by the larvae of  
*Pissodes approximatus*

Stage	Time (days)	Average length of larval mines (in.)
Egg	8.6±1.6	
1st. instar	3.6±0.5	0.31±0.1
2nd. "	3.9±0.8	0.86±0.4
3rd. "	4.9±0.9	1.42±0.7
4th. "	24.0±6.1	9.96±2.4
Pupa	14.8±0.7	

to a medium brown. The first adult emerged in cages in 1956 on July 26 followed by a sustained high emergence from about August 15 to September 10. The sex ratio of emerging adults was approximately 1:1. The new adults feed from the time of emergence until the onset of cold weather, but the females do not mate or oviposit until the following summer.

Logs infested in June, 1956 produced an average of 216 adults per square foot of bark, while logs infested in early September produced only 51 adults per square foot of bark. It must be remembered, however, that the relative percentage of each stage overwintering depends to a large extent on the time of the year the breeding material becomes available to the weevils. In southern Ontario, where large *P. approximatus* populations are usually associated with Christmas tree cuttings, the stumps of trees cut in the fall are invaded by the weevils in late May and early June the following year, and this results in a large emergence of adults in August and September. Breeding material available to the weevils later in the summer is therefore relatively limited, resulting in only a few overwintering larvae and pupae.

#### Controlling Factors

Since *P. approximatus* is a secondary insect not capable of attacking healthy pines successfully, the main factor controlling its population density is the availability of suitable breeding material. Under natural conditions this factor keeps the weevil population low. In areas where pines are grown in pure stands and the stumps of harvested trees are left in the field to rot, populations build up to epidemic proportions.

There are several other factors of lesser importance that operate in controlling the population of *P. approximatus*. During the 1956 growing season it was found that up to 35 per cent of the larval population was killed by a vipionid ecto-parasite belonging to the genus *Coeloides*. Sap suckers and woodpeckers are also of considerable importance. They are capable of devouring large numbers of larvae, pupae, and adults from under the bark, particularly in trees where the stem is heavily infested throughout its length. In 1956 the downy woodpecker, *Dendrocopus pubescens medianus* (Swainson), was observed to destroy up to 90 per cent of the weevil population in individual trees by completely stripping the bark from the stem and large branches in search of food. Weevil populations in stumps, however, were found to be practically free from attack by birds; they are nevertheless subject to serious competition

from two bark beetles, *Dendroctonus valens* Lec. and *Ips pini* (Say), and the pales weevil, *H. pales*.

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### Effects of 1956 Spring and Summer Temperatures on Spruce Budworm Populations (*Choristoneura fumiferana* Clem.) in the Gaspé Peninsula<sup>1</sup>

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#### Introduction

In 1956, the spruce budworm infestation which had been in progress in the Lower St. Lawrence and Gaspé Peninsula for about eight years, covered the whole territory from the Rimouski River to the eastern tip of the Peninsula (Fig. 1). In many localities throughout the region repeated defoliation had been severe enough to cause some trees to die (3). Had it not been for the extensive aerial spraying operations practised in this region since 1954, tree mortality would undoubtedly have been even more widespread.

Until 1957, insect populations were maintaining themselves at high levels in unsprayed territories and were gradually re-invading those that had been sprayed. In 1957, a considerable reduction was noted in the number of spruce budworm over a territory of 1,600 square miles in the region of the Shickshock Mountains which represents approximately 20 per cent of the area under infestation (Fig. 1). Observations made in the course of biological studies with respect to the spraying program in this region indicated that the reduction was due to the unusually cool weather that prevailed during the spring and summer of 1956. These observations were based mainly on the early larval population surveys conducted

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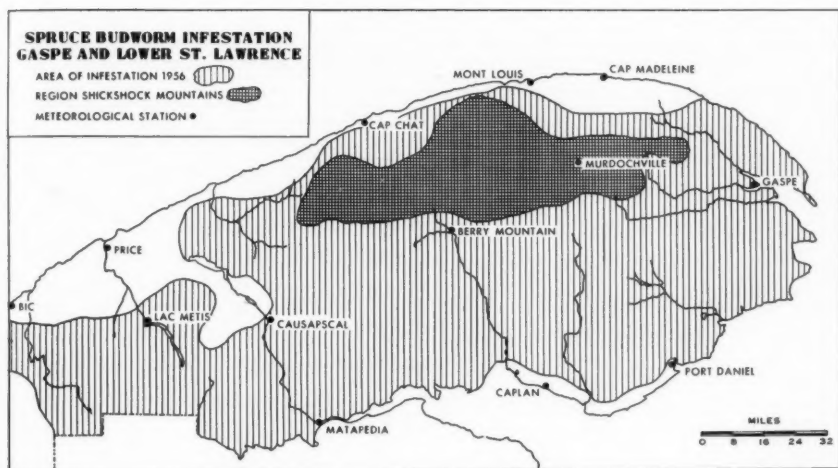


FIGURE 1

under the direction of the author, and on the egg-mass surveys conducted under the direction of R. Martineau in 1956 and 1957. These surveys took place in both sprayed and unsprayed localities throughout the region. Early larval populations were assessed by counting the insects on one 18-inch branch tip taken by means of pole pruners from the mid-crown of each of five dominant balsam fir trees from each of a number of localities. The egg-mass surveys were conducted according to the sequential sampling technique developed by Morris (8). In addition to the regular egg-mass survey in 1956, a number of localities were sampled for eggs by the author in the region of the Shickshock Mountains in November.

#### Weather Records

Table I gives the mean temperature (Fahrenheit) for May, June, July, and August 1956, for 13 localities (Fig. 1) and the divergence from the overall mean for 11 localities in the Lower St. Lawrence and Gaspé. The mean 1956 temperatures were calculated for each locality for each month by adding the mean maximum and mean minimum temperatures and dividing by two. The divergence from the overall mean was obtained by comparing the 1956 monthly mean with that obtained for all years of recorded temperatures for each of 11 stations. In all stations where divergence from the overall mean was noted the temperature was below normal for all four months. Berry Mountain Depot and Murdochville were newly established stations, and for this reason, it was impossible to compare the 1956 data from these stations with those of other years.

Table II gives the precipitation in inches for May, June, July, and August for 1956, and divergence from the normal for each of 11 localities. Precipitation for any one month varied somewhat between localities but when the area as a whole is considered the monthly precipitation did not differ greatly from the normal. Precipitation in July was equal to the normal, while in May, June, and August is was slightly less than normal.

Weather records for September and October are not given in detail for the region as a whole since in most localities the life-cycle of the spruce budworm

TABLE I

Mean<sup>(1)</sup> Temperature (Fahrenheit) for May, June, July, and August 1956, and Divergence from Overall Mean<sup>(2)</sup> for Various Stations in Lower St. Lawrence and Gaspé.

Station	No. of years of meteorological observation	Mean monthly temperature for 1956 and divergence from overall mean							
		May		June		July		August	
		Mean	Diver.	Mean	Diver.	Mean	Diver.	Mean	Diver.
Berry Mountain	1	37	—	52	—	58	—	52	—
Bic	50	44	-4.5	56	-2.8	60	-3.7	59	-1.3
Cap Chat	46	42	-2.6	52	-3.2	58	-3.4	57	-1.1
Caplan	8	43	-4.4	56	-2.0	61	-3.4	59	-1.9
Cap Madeleine	51	41	-3.8	54	-2.0	59	-3.2	61	-3.4
Gaspé	36	42	-2.3	55	-5.2	61	-6.7	58	-4.4
Causapscal	37	42	-6.0	57	-1.7	59	-3.8	57	-1.8
Lac Metis	28	—	—	55	-2.8	58	-4.4	57	-1.5
Murdochville	3	35	—	51	—	56	—	56	—
Matapédia	26	42	-4.8	57	-3.8	61	-3.8	57	-2.3
Mont Louis	19	41	-5.4	53	-4.4	62	-2.4	63	-3.2
Port Daniel	28	42	-2.5	53	-3.8	59	-5.2	58	-2.0
Price	23	43	-4.4	57	-1.7	60	-3.8	59	-2.7
Average		41	-4.1	54	-3.4	60	-4.0	58	-2.3

<sup>1</sup>Calculated by adding mean maximum and mean minimum temperatures and dividing by 2 for each month.

<sup>2</sup>Average for all years of observations for each month.

TABLE II

Precipitation in Inches and Divergence from Average<sup>(1)</sup> Precipitation for May, June, July, and August 1956 for Various Stations in Lower St. Lawrence and Gaspé.

Station	Precipitation in inches and divergence from mean							
	May		June		July		August	
	Pre.	Diver.	Pre.	Diver.	Pre.	Diver.	Pre.	Diver.
Bic	2.77	+0.15	2.01	-0.97	3.22	+0.11	2.75	-0.06
Cap Chat	2.30	-0.24	2.49	-0.66	4.78	+1.52	2.97	+0.07
Caplan	2.56	-0.70	3.53	+0.59	4.23	+0.59	3.70	+0.30
Cap Madeleine	0.56	-2.08	5.04	+2.21	2.11	-1.03	2.40	-0.62
Gaspé	0.75	-2.24	4.15	+1.33	2.64	-0.42	3.95	+1.12
Causapscal	2.58	+0.39	3.35	+0.21	3.09	-0.71	2.54	-0.66
Lac Metis	3.35	+0.60	1.87	-1.72	5.04	+1.01	2.11	-1.46
Matapédia	2.43	-0.59	3.27	-0.38	3.17	-0.79	3.55	-0.31
Mont Louis	0.20	-2.31	—	—	1.18	-1.85	2.23	-0.72
Port Daniel	2.23	-1.19	3.51	+0.35	4.46	+1.08	4.65	-0.81
Price	2.28	-0.34	2.68	-0.95	3.45	+0.08	2.70	-0.56
Average	2.03	-0.72	3.19	+0.01	3.40	-0.41	3.50	-0.34

<sup>1</sup>Average for all years of observations for each month.



TABLE III

Mean Maximum and Minimum Temperatures, Mean Monthly Temperature (F°), and Mean Precipitation (Inches) for September and October 1956 for Two Stations in the Vicinity of the Shickshock Mountains, Gaspé.

Station	Month	Mean max. temp.	Mean min. temp.	Mean monthly temp.	Precipitation
Berry Mountain Depot	Sept.	61	34	47	2.35
	Oct.	55	29	42	1.51
Murdochville	Sept.	60	38	49	2.03
	Oct.	51	33	42	1.36

was completed at that time. At higher elevations, however, the insect was still active, and the records for two newly established meteorological stations in the immediate vicinity of the Shickshock Mountains (Berry Mountain Depot, and Murdochville) are shown in Table III. These records indicate that the days were relatively warm and sunny in September and October, while the nights were generally cold and frosty. At Berry Mountain Depot frosts were recorded for 13 nights in September, and 16 nights in October.

#### Status of the Insect in 1956

In the spring of 1956 emergence of the overwintering larvae began a week to ten days later than in previous years, about May 27 at the lower elevations and about June 8 in the region of the Shickshock Mountains. The average population per 18-inch branch tip for 56 unsprayed localities was 23.4 for the region as a whole; for 13 localities sampled in the region of the Shickshock Mountains it was 31.9 (Table IV).

In 1956 development of the insect was greatly retarded. At lower elevations it was two weeks behind that of 1955; the peak of adult emergence took place about July 30 in the western sector and about August 7 in the eastern sector. Oviposition took place over a period of three weeks from approximately July 23

TABLE IV

Average Number of Insects per 18-Inch Branch Tip Taken at the Time of the Third Instar in 1956 and 1957 for Various Unsprayed Regions in the Lower St. Lawrence and Gaspé.

Region	Year	No. localities sampled	No. of 18-inch branches	No. of larvae per 18-inch branch
Lower St. Lawrence and Gaspé.....	1956	56	280	23.4
Shickshock Mountains....	1956	13	65	31.9
Lower St. Lawrence and Gaspé.....	1957	59	295	34.0
Shickshock Mountains.... (valleys)	1957	9	45	4.4
Shickshock Mountains.... (elevations)	1957	11	55	0.8

to August 15. In the region of the Shickshock Mountains development was even more retarded; by mid-July pupation had not yet taken place and by the end of August 50 per cent of the pupae were still unemerged. Oviposition occurred mostly in September, over a period of several weeks.

In August and September of 1956, a spruce budworm egg survey was conducted as in past years throughout the Gaspé and the Lower St. Lawrence with the purpose of predicting populations for 1957 (3). A total of 612 localities (approximately one-half in sprayed and one-half in unsprayed areas) were sampled. Morris (8) estimated that a population of 200 egg-masses per 100 square feet of branch surface generally will give rise to a population capable of severely defoliating the following year's shoot growth. In the majority of the unsprayed localities the egg population was very heavy, the average number of egg-masses per 100 square feet of branch surface being 418. In the region of the Shickshock Mountains over 75 per cent of the 52 localities sampled outside of sprayed areas showed the egg population to be in the severe category, with an average of 326 egg-masses per 100 square feet of branch surface. However, the average number of eggs in 100 clusters examined was found to be only  $11.0 \pm 0.8$ , which is somewhat lower than some previous records obtained in New Brunswick (8) and in northwestern Ontario (1), where the average number was close to 20.

When the region of the Shickshock Mountains was visited in early November, all egg-masses in the valleys or at altitudes below 1,500 feet were hatched while at higher altitudes many unhatched egg-masses were found. One full-length branch was obtained from the mid-crown of each of five balsam fir trees from each of eight localities varying in altitude between 1,800 and 2,500 feet in the vicinity of Brandy Brook, Ste. Anne Lake, and Madeleine Lake. The branches were carefully examined for pupae, pupal exuviae, and for eggs.

Thirteen per cent of the pupae were unemerged, and when 63 of these were kept at room temperature, two *Phaenogenes hariolus* (Cress.) and three *Itopectis conquisitor* Say were obtained in mid-November. These parasites usually emerge about the end of July in the Gaspé, but in 1956 were reared during the second week in August from pupae collected at lower elevations. After three weeks' exposure at room temperature the unemerged pupae were dissected. Fifty per cent contained dead hymenopterous parasites, the other 50 per cent had died as pupae in varying degrees of development.

In the eight localities sampled the egg-mass population was very high and ranged from 509 to 814 egg-masses per 100 square feet of branch surface. Of these egg-masses, 53 per cent were unhatched, 10 per cent partially hatched, and only 37 per cent totally hatched. In two localities as many as 80 per cent of the eggs were unhatched. The unhatched egg-masses gave the appearance of being healthy, but when 150 of them were kept at room temperature they soon showed signs of desiccation and none produced larvae. The non-viability of the eggs could not be attributed to their not having been fertilized since embryonic development was quite advanced in many of them.

In November 1956, a total of 86 unemerged egg-masses were marked by tagging the twigs on which they were found. These egg-masses were left *in situ*, and when they were re-examined on June 24, 1957, 60 per cent of the masses were dead and the remainder were missing. The masses remaining on the branches were dark brown and scale-like, and were readily detached from the needles. It is most probable that the missing masses had died before dropping off the needles.

Although the unusually cool weather that prevailed in the spring and summer of 1956 was largely responsible for the drastic retardation in the development of the spruce budworm at high altitudes, it was not the only factor involved. The year 1956 was one of heavy flower production for balsam fir and the spruces throughout Gaspé. As a consequence of this heavy flower production, shoot growth was much reduced especially on balsam fir (7). The staminate flowers provided favourable food conditions for the early larval instars (1) (4), but when the flowers were spent the larvae quickly consumed the meagre current year's foliage. Once all the current year's growth was consumed, the larvae had no alternative but to feed on the old foliage. As a consequence, approximately two years' growth was destroyed on balsam fir, white spruce, and black spruce trees in the region of the Shickshock Mountains. It has been shown that a diet of old foliage greatly retards development of the insect (1). Therefore, the situation that prevailed because of poor weather was aggravated by a shortage of proper food. This would also explain the occurrence of the small egg-masses referred to above since Miller (6) found that, if a population is subject to larval starvation, the resultant small adults tend to lay smaller egg-masses.

#### Status of the Insect in 1957

About the third week in June, in 1957, early larval population counts were made in nine localities in valleys, and eleven localities at elevations above 1,800 feet in the region of the Shickshock Mountains. The average number of larvae per 18-inch branch tip for localities at lower elevations and those at higher elevations was 4.4 and 0.8 respectively. As can be seen populations were almost six times greater at lower than at higher elevations. However, even at the low elevations populations were considerably less than those of the previous year for the same area, or those of the same year for other areas in the Gaspé (Table IV).

Even after the reduction in the egg population due to mortality at the higher elevations in the fall of 1956, enough larvae had emerged to constitute a large population the following spring. Furthermore, in the valleys where the egg count had been high and where there had been no egg mortality, the larval population in the spring of 1957 should have been very high. Evidently, populations of the spruce budworm were affected at all elevations in the region of the Shickshock Mountains by some factor or complex of factors which acted in the interval of time between egg hatching in the fall of 1956 and establishment of the larvae in the spring of 1957.

Weather conditions in winter or spring, even when extreme, do not appear to be seriously detrimental to spruce budworm. It is known that this insect can withstand prolonged winter temperatures of 40 and 50 degrees below freezing. Also, in the spring of 1953, very unfavourable weather conditions caused the almost complete disappearance of a forest tent caterpillar (*Malacosoma disstria* Hbn.) infestation over a territory of 43,000 square miles in Central Canada (2), yet, these same conditions apparently had no effect on the spruce budworm that was in an epidemic state throughout most of the territory. Late spring frosts occasionally affect the insect indirectly by killing the young shoots on balsam fir and white spruce, thereby depriving the larvae of food (4), but this did not occur in the spring of 1957 in the Gaspé.

It is probable that the same conditions that prevented some of the eggs from hatching in the region of the Shickshock Mountains in the fall of 1956,

were responsible for the mortality of first-instar larvae. On emerging from the eggs the larvae immediately spin hibernacula, and this usually takes place in early August when the weather is considerably warmer than in September, at which time emergence occurred in the mountainous regions in 1956. In these regions conditions for hatching, even in the valleys, were certainly marginal, and it is likely that, even if the larvae succeeded in emerging, their activity would have been arrested by the cold fall weather with subsequent failure to establish hibernacula. Another factor that might have been of importance in causing the eggs and the young larvae to die is the amplitude of the September temperature changes. At Berry Mountain Depot, a maximum of 78°F. was recorded for September 5, 6, and 7, while a minimum of 24°F. was recorded for September 9 and 10.

Throughout the summer of 1957, the action of the many biological and physical factors that normally affect the late-instar larvae and pupae of the spruce budworm further reduced the already heavily diminished population. At the time of the late pupal stage in 1957, populations were again counted in the same manner, and on the same trees that were sampled for the early larval population survey in the 11 localities in the valleys and in the nine localities at the higher elevations. The residual population per 18-inch branch was very low; an average of 0.1 and 0.03 insects was obtained for localities in the valleys and at high altitudes respectively.

An egg-mass survey was again conducted throughout the area in August of 1957. Although a reduction in egg population occurred in a number of sectors, it was especially pronounced in the region of the Shickshock Mountains. In this region a total of 42 localities were sampled in unsprayed areas; in 60 per cent of these localities no eggs were recorded, and in the remainder the egg population was light. There was an average of 10 egg-masses per 100 square feet of foliage for the 42 localities sampled. The magnitude of the reduction in population can best be appreciated when this figure is compared with that obtained in 1956 for the same region and referred to earlier, namely an average of 326 egg-masses per 100 square feet for the 52 localities sampled.

The aerial defoliation survey was conducted throughout the Lower St. Lawrence and Gaspé in August 1957. The aerial observations were confirmed by ground observations along all passable roads. Results of this survey indicated that the defoliation of the current year's growth was light (less than 10 per cent) for the region of the Shickshock Mountains while it was mostly severe (75 to 100 per cent) elsewhere (5).

#### Discussion

It is impossible to predict the final outcome of the drastic reduction in population of the spruce budworm in the region of the Shickshock Mountains. The residual population in this area may gradually increase to the point where numbers are again sufficient to cause serious damage to the forests, but, it is even more likely that the area will be re-invaded, in time, by insects coming from the surrounding heavily infested territories. In any event, the coniferous stands will benefit from a reduction in defoliation for some years to come, and many seriously weakened trees will show recovery.

#### Summary

In 1956, all coniferous stands in the Lower St. Lawrence and Gaspé were infested by the spruce budworm, and in many regions repeated defoliation had caused considerable damage. That year, throughout the region, temperatures

for May, June, July, and August were much cooler than normal; consequently, insect development was greatly retarded. In some regions, there was a shortage of current year's foliage on balsam fir and the spruces, and because the larvae were forced to feed on old foliage their development was retarded further. At higher elevations, in the Shickshock Mountains, development was retarded to the point where some pupae, and a considerable number of eggs failed to emerge before the onset of the cold autumn weather. Indications are that the same conditions that killed some of the eggs also killed many first-instar larvae. As a result, populations of this insect were very low in the region of the Shickshock Mountains in 1957. Elsewhere in the Gaspé, populations were high and there is no reason to believe that the infestation is coming to an end.

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Mr. R. Martineau of the Forest Biology Laboratory in Quebec provided valuable data on egg populations. Dr. L. Daviault, Officer in Charge of the Forest Biology Laboratory in Quebec, and Dr. W. G. Wellington, Head Bioclimatology Section, Division of Forest Biology, very kindly reviewed the manuscript.

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## Studies of Flight and Attack Activity of the Ambrosia Beetle, *Trypodendron lineatum* (Oliv.), and other Scolytids<sup>1</sup>

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### Introduction

The flight habits of any scolytid beetle are an important aspect of its biology, and times of flight should be known for effective chemical protection of logs against its attacks. Consequently, during the course of biological and chemical control investigations of the ambrosia beetle, *Trypodendron lineatum* (Oliv.), from 1954 through 1956, much attention was directed to a study of its flight activity. This species is well known to attack early in the spring. There are other attack flights later in the season but far fewer beetles are involved then. The beetles also fly at the time they leave the brood logs to enter forest litter, where they overwinter. Several methods were used to study the influence of weather, season, and other factors on flights of *Trypodendron* and, to a lesser extent, of other scolytids. These methods and some of the data secured are described and discussed in this paper.

### Methods

The work was carried out near Cowichan Lake, B.C., in a semi-mountainous area where active logging operations of the clear-cutting type have been carried out for many years and in which high population levels of *Trypodendron* occur. Attack densities of one hundred galleries per square foot of log surface are not uncommon. The 1954 studies centred in and around a site clear-cut the previous autumn (Site 1). The following year most work was done in a near-by location within standing timber thinned by wind-throws and the cutting of some 25 trees for experimental material (Site 2). Figures 1 and 2 illustrate the nature of these sites, which are about 1,600 and 1,500 feet in altitude, respectively. Other 1955 studies were carried out around active logging operations within 2 miles of the main study area, as were the much more limited observations of 1956. Weather data were taken from instruments of the British Columbia Forest Experiment Station, about 6 miles away, at the level of Cowichan Lake (altitude 527 feet).

Much information on aerial populations of beetles in the study areas was obtained with glass barrier "window" traps described previously (Chapman and Kinghorn, 1955). These traps consist of a transparent barrier formed by a piece of window glass set in a wooden frame, with a sheet-metal trough hanging below. Insects that strike the glass and fall or lose height while flying against it collect in the trough which is filled with water, with oil or a wetting agent added. Traps were placed with centres about 5 feet above the logging slash and debris of Site 1 and between trees around Site 2. Collections from them were usually made twice weekly in 1954 and daily in 1955. In 1954, some traps with barriers painted with colours or patterns of black and white were tested.

Other sources of information on flight activity included direct observations, collecting pans and cloth trays, and emergence containers. The pans, containing oil and water, were placed beneath heavily attacked logs. The cloth trays, 18 inches square and 3 inches deep, were mounted under several logs sprayed with lindane at each site. Collections of dead and dying beetles which fell from the sprayed logs provided much data on times of beetle attack. Portions

<sup>1</sup>Contribution No. 444, Forest Biology Division, Science Service, Department of Agriculture, Ottawa, Canada.



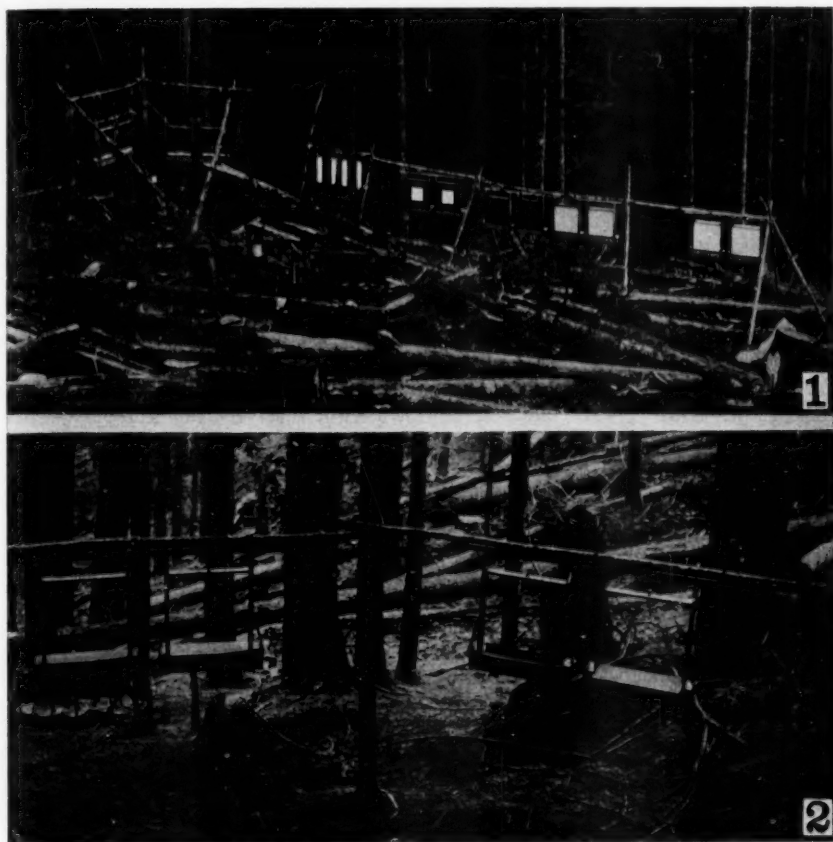


Figure 1. Glass and painted barrier traps in 1954 study area. Photo by R. Banyard.

Figure 2. Glass barrier traps at edge of 1955 study area.

of attacked logs were placed in waxed cardboard containers from which emerging beetles were collected by glass vials inserted in the walls.

#### Results and Discussion

It is desirable, first, to consider the effectiveness of the sampling methods used.

##### *Flight traps*

The effectiveness of the glass barrier traps is difficult to evaluate, and we can add only a little to the comments given previously (Chapman and Kinghorn, 1955). Speed and direction of wind, and direction, speed, and manner of flight of the insects all influence trap efficiency. Amount of reflection from the essentially invisible glass barriers varies with their location and orientation and, presumably, can influence capture of certain insects. Field observations led to the conclusion that with traps placed in the open, only about a fifth of the beetles which would normally have flown through the glass-occupied space actually struck the barrier. To test this, the number of beetles that flew

TABLE I  
Effect of light on numbers of insects taken by barrier traps at lake-side station  
May 31 — October 23, 1954

	Ultra-violet light	Incandescent light	No light
<i>Trypodendron</i> .....	45	14	14
Other Scolytidae.....	337	187	251
Other Coleoptera.....	319	131	214
Lepidoptera.....	3547	1409	191

through an empty frame were compared with those taken by a complete trap next to it. During successive 10 to 15 minute intervals the numbers were, respectively: 5-2; 66-9; 29-8; 27-11; 20-11; 8-3; 7-2; 12-5. It appears that many beetles either avoid the traps or recover and fly away after striking the glass. For several reasons, therefore, such traps cannot furnish quantitatively precise data on flying insect populations.

There is no doubt, however, that the Coleoptera, being in general compact and heavy-bodied, with slow, steady flight and little ability to change direction quickly in the air (e.g., Rüschkamp, 1927) are among the most likely insects to be taken in this way. This was indicated by the experience of Rice (1933) and Wakeland (1934) with screen barrier traps, for example, and is borne out by our observations on glass barrier trap operation and by the numbers and variety of beetles in the trap samples. Other insects, such as bumble-bees, which fly fast and hit the glass hard, heavy-bodied moths, or weak fliers such as winged termites, are likely to be taken by these traps, and surprising numbers of both higher and lower Diptera occurred in trap samples. The traps are a useful addition to other methods of sampling flying insect populations (see Hoffman *et al.*, 1949; Peterson, 1953; Johnson and Taylor, 1955).

Incandescent and ultra-violet (G.E. black-light fluorescent tube) lights of similar power were mounted on one side of glass barrier traps and kept operating constantly at the field laboratory near the weather station during three months in 1954. As would be expected from the location, far fewer *Trypodendron* were taken by an adjacent unlighted control trap than by any traps at the study sites (Table I, cf. Fig. 3). The ultra-violet light seems to be attractive to *Trypodendron*, and lights attract some scolytids (Balachowsky, 1949; Frost, 1953; Osborne, 1956), but the heaviest *Trypodendron* flights take place early in the season when temperatures high enough for this activity occur only during daylight hours. It would probably not be worth while, therefore, to use lights with these traps for this species. The painted barrier traps (Fig. 1), made of hardboard (Masonite) with smooth surface exposed, took varying numbers of scolytids, but with the exception of *Dendroctonus valens*, their catches were less than those of adjacent glass barrier traps (Table II).

#### Cloth trays

The cloth trays gave data only on those insects which crawled on or attacked the sprayed logs, but proved very useful for such species. *Trypodendron* characteristically walks about on logs for some time before starting its galleries, and if logs are covered with contact or fumigating insecticide, this behaviour

TABLE II

Numbers of scolytids taken by glass and adjacent painted hardboard barrier traps for entire 1954 season

Insect	Glass	Painted barrier		Natural colour (brown)	Green <sup>1</sup>	Yellow <sup>1</sup>
		Vertical white and black bands	White square in black			
<i>T. lineatum</i> . . . . .	3607	1056	1637	1467	884	546
<i>Dendroctonus valens</i> . . . . .	26	32	69	74	46	56
<i>D. pseudotsugae</i> . . . . .	156	50	70	49	59	52
<i>Pseudohylesinus</i> spp. . . . .	1024	224	321	487	429	271
<i>Hylastes-Hylurgops</i> spp. . . . .	874	239	419	381	305	217

<sup>1</sup>Sherwin-Williams Milan Green and Canary Yellow.

results in much mortality. Although beetles were often alive when found in the cloth trays, they were generally too weak and poorly co-ordinated to crawl or fly out. The numbers of beetles in the trays reflect both intensity of log attraction and effectiveness of the insecticide but, if the latter is constant, this method gives a good picture of flight activity at different times and around different logs. When relatively few beetles are present, poisoned trap-logs with collecting trays beneath seem to give a better indication of flight activity than do the flight traps.

#### Other sampling methods

Direct observations were frequently made during the course of this work and provided a rough check on other methods during periods of heavy flight. They lost importance for this purpose, however, when only a few beetles were flying.

Moericke's coloured pan sampling method (e.g., Moericke, 1955) was tested. Pans painted red, orange, yellow, green, purple, black and white were filled with water and fuel oil and set on the ground in logging slash during the heavy 1954 attack periods. There was no indication that beetles were attracted to any pans, however, as none took more than five beetles during periods when near-by barrier traps were taking several hundred each. The water-oil emergence pans beneath logs function by taking the many beetles which, when they are leaving the brood logs, drop or fall to the ground before flying to their overwintering site.

#### Early spring flight

Figures 3 and 4 present data on *Trypodendron* flight during 1954 and 1955 in relation to weather. Collections from traps were made in the early morning before any scolytid flight had commenced and, therefore, represented activity since the time of the previous collection. This and the use of three- or four-day collection intervals in 1954 somewhat obscured the true picture of daily activity, but the general pattern of flight in relation to weather is quite clearly shown.

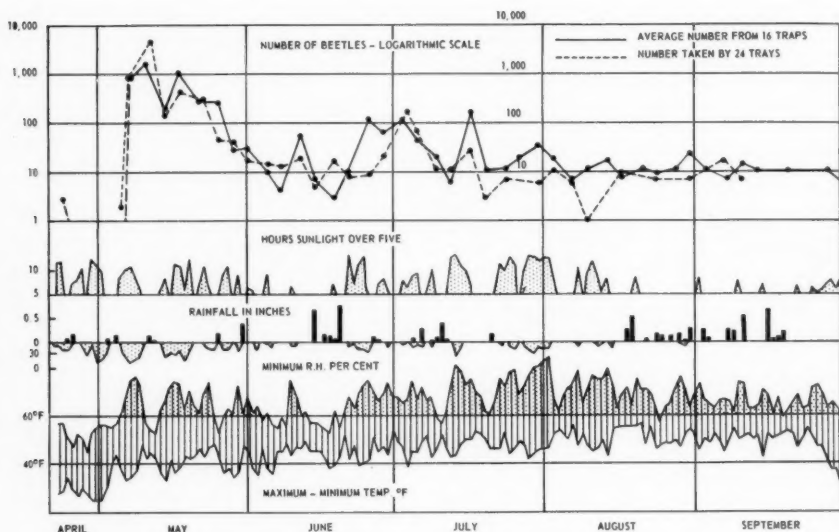


Figure 3. Flight activity of *Trypodendron* in relation to 1954 weather, based on flight trap and sprayed-log collecting tray records.

The spring of 1954 brought conditions which caused huge swarms of scolytids and many other beetles and insects to appear more or less simultaneously in areas where logs felled the preceding autumn were abundant. The heavy "swarming" resulted from the relatively sudden change from cool and cloudy to warm and sunny weather. On May 5, during one hour's observation at Site 1, a few flies, bumble-bees, and *Pseudohylesinus* were flying about but no *Trypodendron* were seen and only one was found in the cloth collecting trays. At the same location and time of day on May 6, however, tremendous numbers of scolytids, mostly *Trypodendron*, were flying over the felled logs and logging slash. Dozens of beetles could be seen in the air in any direction. They alighted on clothing as fast as they could be picked off and were seen crawling in numbers on most logs in the area. *Pseudohylesinus nebulosus* (Lec.) was also very abundant. The May 7 trap collection represents a single day of activity (May 6) while that of May 10 covered a three-day period. The actual peak of flight activity, therefore, occurred on May 6, in the early part of the first intense warming period of that spring.

A quantitative indication of the aerial population density occurring in a situation similar to this was obtained in the spring of 1957 during the initial testing of a rotating net device. Two 20-inch diameter nets mounted at the ends of a horizontal arm were swung approximately six feet above logs and slash of the preceding winter's felling. The diameter of the sweep was 18.8 feet, and the net speed was about 13.4 m.p.h. On May 5, when large numbers of beetles were flying, the net took a total of 40,930 *Trypodendron* during 11½ hours. Half-hourly collections ranged from 645 to 5,429 specimens, with a mean value of 2,394 for 16 twenty-five minute periods when the slope was directly sunlit, the air calm, and the temperature higher than 60°F. These catches can be expressed as a density per unit volume of air, by dividing the

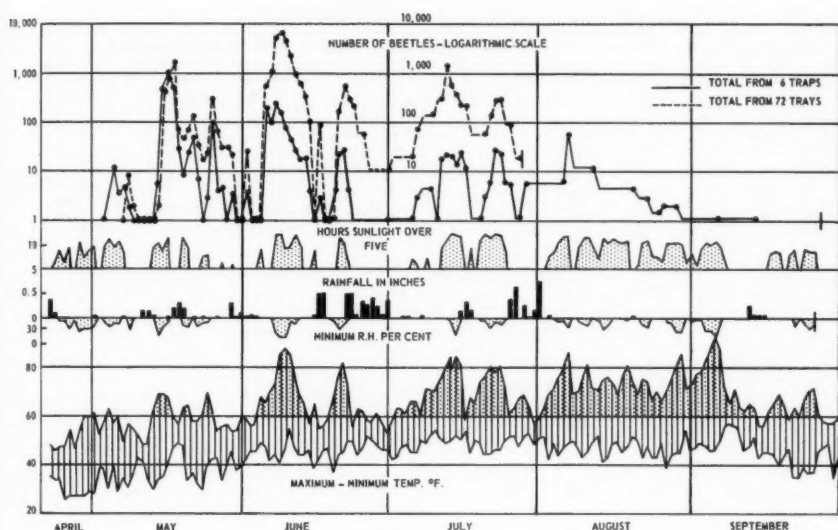


Figure 4. Flight activity of *Trypodendron* in relation to 1955 weather, based on flight trap and sprayed-log collecting tray records.

number of insects caught by the estimated volume of air sampled during the collection period. The calculated insect densities during the sample periods ranged from 0.13 to 1.08 per cubic yard, with a mean value of 0.48 per cubic yard. Although these values are only approximations, they give greater meaning to our description of spring "swarming".

The 1954 "swarming" continued through May 7, 8, and 9, after which cool rainy weather occurred. Heavy flights of *Trypodendron* and *Pseudohylesinus* were repeated May 14-19. During these periods, particularly after May 7, many other bark- or wood-inhabiting insects were abundant including other scolytids (*Dendroctonus*, *Hylurgops*, *Hylastes*, and *Ips* species) and curculionids, clerids, cucujids, cerambycids, staphylinids, and winged carpenter ants. Flight trap and cloth tray catches adequately reflect the enormous numbers of insects flying about at these times, although the use of a logarithmic scale in Figures 3 and 4 tends to obscure the magnitude of this flight activity as compared with that later in the season. The numbers of several groups of Coleoptera increased again during a third warm period around the end of May (Fig. 5) but there was no peak in *Trypodendron* catches then, probably because so many individuals had already emerged from overwintering quarters and attacked logs. The 1955 records also show well-defined attack periods (Fig. 4), although the aerial density of beetles was far less than in 1954, presumably because of the much smaller amount of attractive log material. It is not clear why the trays took relatively more beetles than the traps during the June as compared with the May attack period, but it appears that temperature could be a factor in this difference, from the standpoint of beetle behaviour, of insecticide action, or both. From observations in 1954 and other years it is plain that in this area, as elsewhere (Hadorn, 1933), emergence of this insect occurs at any one site during relatively brief periods in the spring.

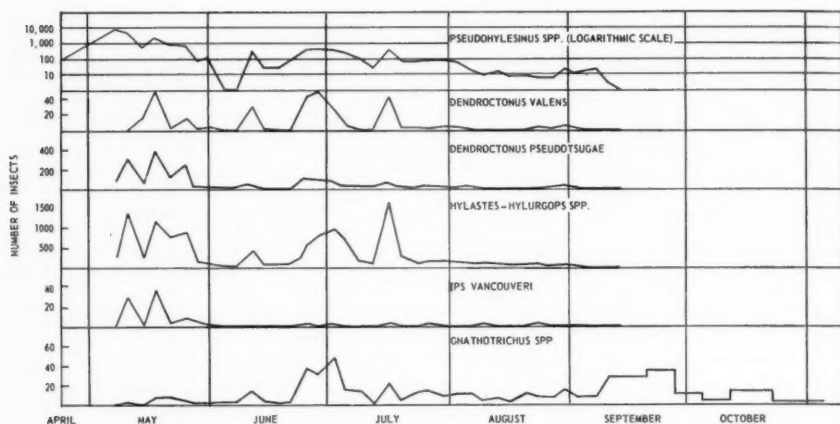


Figure 5. Flight activity of various scolytids in 1954 study area, based on catches from 16 glass traps. Autumn *Gnathotrichus* records averaged to correspond to earlier collection periods.

On the basis of the trap and tray records and other observations we conclude that when air temperature rises above 60°F. (15.6°C.), after most of the snow has melted, the first heavy attack flights of *Trypodendron* can be expected. However, small numbers will appear at temperatures a few degrees below this figure (cf. Hadorn). We have found consistently that *Pseudohylethinus nebulosus* starts to fly at lower temperatures than *Trypodendron* and, therefore, its appearance in the spring indicates impending flights of the latter. Nevertheless, because of the variable spring weather in this region, it is difficult to predict the first *Trypodendron* flights. Spring air-mass movements similar to those causing periods of intense drying and fire hazard later in the season often occur. At such times relatively warm dry air from interior continental regions moves over the coast (Turner, 1953). Early in the season the resulting marked weather changes, which may differ considerably in extent and time of appearance from year to year, can result in mass emergence and flights of many scolytids and other insects.

The times of early flights are also related to altitude. On Vancouver Island, logging operations may be carried out from sea level to around 3,000 feet. At higher logging sites there is usually still much snow when attacks occur at lower altitudes. A period of weather in which early warming continues can therefore lead to events like those observed in 1956. In that year heavy attacks occurred before mid-April at the level of Cowichan Lake, but at higher altitudes snow cover was still heavy and remained so, especially on shaded sites, long after air temperatures were suitable for *Trypodendron* flight. As the season progressed and the snow gradually melted, *Trypodendron* emerged at higher and higher altitudes over a period of several weeks. Portions of logs protruding from snow were attacked and beetles emerged in numbers from litter in spots where snow had melted, as at bases of trees, within a foot or two of snow banks. There was some flight activity in the general area for many weeks, with peaks undoubtedly occurring some time between mid-April and mid-June, depending on specific location and altitude.



The importance of the proximity of attractive logs for trap sampling was emphasized in 1956. In that year traps placed next to a series of experimental logs which were never attacked failed to take more than an occasional *Trypodendron*, although high populations were known to have emerged from litter within a few hundred yards. A pair of traps left mounted in one place during the 1954 and 1955 attack periods took 1,393 and 151 beetles, respectively. Logs near the traps were attractive only in 1954, and it is likely that most beetles taken in 1955 had overwintered at the site and were flying elsewhere when taken. During an attack period these beetles fly around attractive logs, alighting, crawling about and then flying again, apparently using trial-and-error selection of the final burrowing site. For this reason the closer traps are to such logs, the more beetles they will take. This important point should always be considered in forming conclusions, based on trap catches, on seasonal flight activity of various scolytids. It is known, moreover, that heavy attacks can soon change the attractiveness of logs for many species of scolytids, and traps near such logs would then give an incomplete picture of the time and duration of their flight activity.

The various scolytid species have characteristic flight periods (e.g., Balachowsky, 1949), and the 1954 flight trap records provide some information on differences in times of flight (Fig. 5). The pattern of flight activity of the two *Dendroctonus* species is somewhat different, for example. Also, the flight pattern of ambrosia beetles of the genus *Gnathotrichus* (mostly *sulcatus*) is clearly different from that of *Trypodendron*. The *Hylastes-Hylurgops* group, treated together because of the difficulty of readily identifying them, undoubtedly presents a complex picture of flight activity because different species are represented. The data on *D. valens* provide an example of the usefulness of the traps. During many hours of observation and net collection during scolytid flight periods only one or two specimens were seen. Trap samples, however, showed that they were actually fairly common in the area.

#### Re-attack flight

Second or re-attack periods were noticed in 1954 and 1955 (June 25-July 5 and July 9-25, respectively), but the numbers of beetles flying during these periods were much smaller than during the initial spring flights. Although *Trypodendron* has only one generation a year, it has two, or even three broods (Hadorn, 1933). These second flights, therefore, are made up of parent adults flying to establish a second brood in other logs. Presumably, beetles taken after re-attack periods in 1954 and 1955 were young adults flying to overwintering quarters. The seasonal history picture was very complex in 1956 due to variation in time of attack at different altitudes. Those beetles which attacked lake-side logs by mid-April, however, started emerging around June 20. In 1954, logs heavily attacked in early spring were not attractive to the re-attack flight, but these beetles were attracted to logs only lightly attacked earlier. In 1955, portions of logs were wrapped with plastic sheeting to protect them from spring attacks. Just prior to the re-attack period, the sheeting was removed; the beetles of the second flight then proceeded to infest the unwrapped wood heavily, although contiguous portions, riddled by earlier attackers, were unattractive. The above observations emphasize the possibility that if there is no attractive material near traps or in an area frequented by observers, re-attack flights may not be noticed.

TABLE III  
Numbers of *Trypodendron* taken by traps at different heights — 1955

Collection interval	Height above ground (feet)		
	5	15	25
May 11 – May 24.....	258	52	6
May 26 – June 30.....	58	6	5
July 1 – July 13.....	10	3	0
July 14 – Oct. 13.....	12	3	2

#### *Flight from brood logs*

The flights from brood logs to overwintering sites were inconspicuous and took place over a long period of time (Figs. 3 and 4), as would be expected from the length of the period during which brood from one attack period becomes mature. Even by summing emergence over several weeks it is apparent that a far smaller number of beetles were taken during their flight to overwintering quarters than at the time of initial attack, whereas the opposite might be expected because of greater numbers of offspring than parent beetles under usual conditions. Part of the 1954 discrepancy could be attributed to removal of most logs from Site 1 before emergence of beetles. There were many experimental logs remaining, however, as well as stumps and slash, and the 1955 logs remained in place all season. Actually, attacking beetles fly around much more than beetles going to overwintering quarters and, where large numbers of attractive logs are present, appear to fly faster and more erratically ("excitedly") than the latter. Either of these factors would result in a greater probability of attacking beetles being taken by the traps than those flying to overwintering sites.

#### *Other features of flight*

Sex ratios were taken on flight trap samples during the 1954 and 1955 seasons. Females generally predominated in 1954, although not by large percentages, whereas the opposite was true in 1955. The seasonal totals of sexed beetles for 1954 and 1955 consisted of 8,265 females and 7,893 males.

Data from the emergence containers and pans showed good agreement with those from the flight traps during the 1954 emergence period.

A set of traps at elevations of 5, 15, and 25 feet, showed, as indicated by observations, that most beetles flew fairly close to the ground at Site 2 (Table III).

The collecting troughs of many traps used in 1955 were covered on one side, thus allowing only insects flying against one side of the glass to be captured. There were usually differences in numbers of beetles taken by adjacent traps, depending on the direction in which they faced. During 1955 three pairs of traps placed just within the timber next to an area clear-cut the previous autumn took 2,529 beetles flying toward and 669 flying away from the clearing. This was a clear and expected difference, but it is difficult to explain some of the results from such traps. At Site 2, for example, four pairs of traps around the experimental log area took 1,073 beetles flying toward and 1,496 flying away from the area, with many of the latter heading in the direction of a near-by clearing, logged several years previously.

During periods of heaviest flight activity in the timber, wind was usually slight and varied frequently in direction. In the open, *Trypodendron* was often seen flying against the wind, even to the extent of losing ground during stronger gusts, which also markedly reduced the numbers of beetles in the air. An observation of a conspicuous late afternoon down-wind flight away from a large number of attractive logs, of *T. lineatum* and other scolytids, indicates that the flight orientation of these beetles needs further study.

#### Summary and Conclusions

Seasonal activity of *Trypodendron lineatum* was studied in relation to site and weather for three years at Cowichan Lake, B.C. Heavy attack flights may be expected when the air temperature exceeds 60°F. (15.6°C.) after most of the snow has melted. The time and extent of early spring warming varies much from year to year in coastal British Columbia. Intense early warm periods may cause first flight activity to occur simultaneously over a wide range of altitude. On the other hand, attack flights may occur over a period of several weeks, at different altitudes, if warming is gradual or if some snow cover remains after the air is warm enough for flight.

*T. lineatum* flights are preceded in the spring by the appearance of *Pseudohylesinus nebulosus*. Many other scolytids may fly during the same warm periods which bring out these insects but in general other species do not appear as early in the season.

At least one re-attack period can be expected after the first brood has developed. Flight activity is most noticeable near attractive logs and these, therefore, should be present in a study area throughout a season in order to secure a valid picture of the flight periods of any species of beetles which seeks such logs. Most flight activity around an area where felled logs occur takes place near ground level.

The flight from brood logs to overwintering quarters is relatively inconspicuous and occurs over a period of several weeks.

The glass-barrier traps provide representative and useful samples of the aerial populations of beetles and many other insects, although there are many factors which influence their effectiveness. Painted barrier traps are not as effective as glass traps for most scolytids. Ultra-violet light seems to be attractive to *Trypodendron* but that from an incandescent source does not.

The use of collecting trays beneath poisoned logs gives a good indication of attack activity of beetles which are attracted to the logs. Coloured collecting pans are of little value for sampling attacking *Trypodendron*. Water pans placed beneath attacked logs, however, take many beetles leaving their brood galleries and can thus be used for determining log emergence periods. Simple emergence containers are also useful for this purpose.

#### Acknowledgments

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### Laboratory Rearing of the Seed-corn Maggot, *Hylemya cilicrura* (Rond.) (Diptera: Anthomyiidae)<sup>1</sup>

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The seed-corn maggot, *Hylemya cilicrura* (Rond.), is a cosmopolitan pest and feeds on a wide range of hosts. The maggots cause extensive damage to seeds and seedlings of beans, soybeans, peas, corn, and cucurbits. Hitherto laboratory investigations have been hampered because the maggot has been very difficult to rear continuously.

Biological studies have indicated that such diverse diets as soybeans (Harukawa *et al.*, 1934), cottonseed meal and fish meal (Reid, 1940), and potato (Leach, 1926) serve to rear the maggot to the adult stage. However, it has been difficult to maintain an adult colony for the time required for mating and oviposition. Reid (1940) used field-collected flies as a source of eggs in his experiments, but failed to get a second generation. Successive generations were reared by Ristich (1950), who provided a high protein diet for adults held in glass cages; in attempts to follow this method at Chatham, only one complete generation could be reared. A more satisfactory method of rearing the species continuously is described in this paper.

#### Materials and Methods

The original supply of puparia was obtained from whole-wheat flour baits and stored at 40°F. and 70 per cent relative humidity as described by Miller and McClanahan (in preparation). When flies were required, the puparia were kept at room temperature, 65° to 75°F., in a cage 10 inches square by 24 inches long, covered with clear plastic film. As the flies emerged they fed from four cotton wicks (No. 2 Absorbent Dental Rolls, 3/8 in. x 6 in.; Johnson and John-

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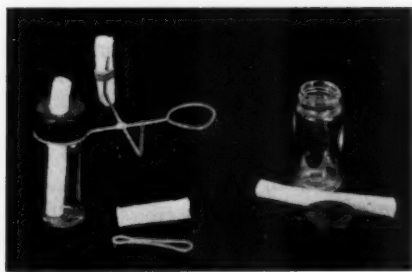


Fig. 1. Feeding unit, partly assembled.

son Ltd., Montreal, Quebec). Distilled water was provided in one 25-ml. vial with a 3-inch wick, and a solution of 10 per cent egg white and 1 per cent sucrose was provided in another vial with a similar wick. One 1½-inch wick was soaked with a 5 per cent yeast suspension, and another with a 1:1:2 solution of molasses, evaporated milk, and water, respectively. The four feeding components were assembled on a wire frame as shown in Fig. 1. Adding yeast to the diet of the adults increased oviposition (Reid, 1940).

Flies, as required, were transferred from the emergence cage to oviposition cages by means of an aspirator inserted through a cotton sleeve at one end of the emergence cage. The oviposition cages were wide-mouthed gallon jars, 6 inches in diameter, with the bottoms removed and the tops covered with cheesecloth. The oviposition units were completed by placing the jars in 9-inch terracotta flower-pot saucers 2 inches deep, containing 3 cupfuls of muck soil. The soil was prepared by sifting through a 15-mesh screen and adding water to give 25 per cent moisture content. Twenty peas, previously soaked for 2 hours, were planted in the soil to feed the developing maggots. Adult food was provided as in the emergence cage.

A number of oviposition units were placed in a galvanized metal tray, 1 inch deep. Water was added periodically to the tray. The water entered a one-sixteenth-inch hole in the centre of each saucer and kept the soil damp. The temperature at the soil surface was  $65^{\circ} \pm 4^{\circ}\text{F.}$ , depending on the room temperature; it was slightly higher inside the jar. Four 20-watt fluorescent lights 10 inches above the tops of the jars provided light from 5 p.m. to 10 p.m. The tray with the rearing cages was kept on a bench with a southwestern exposure. Closed venetian blinds eliminated direct sunlight. Fifty flies were maintained in each oviposition jar, and replacements from the emergence cage were added when necessary. The saucers and the feeding units were changed every 3 to 5 days. Saucers exposed for oviposition were examined, and, if oviposition had been heavy, about 15 additional soaked peas were planted in the soil. A half-inch layer of moist soil was added to all saucers, which were then held in an incubator for 10 days at  $80^{\circ}\text{F.}$  and 80 to 85 per cent relative humidity. The contents of the saucers were then sifted, and all puparia placed in a small dish of soil in the emergence cage.

#### Durations of Stages

The maggot has been reared continuously for two years in the laboratory. The preoviposition period varied from 10 to 20 days; thereafter the flies generally laid eggs until they died. Adults lived up to 6 weeks, but the average



life span was 4 weeks. At 65°F., the egg stage lasted 3 days and at 80°F., the larval period was 8 to 10 days. When puparia were incubated at 68° to 72°F., flies emerged in 4 to 6 days. Mortality in the egg and first instar stages was estimated to be 60 per cent, and the over-all mortality was about 70 per cent.

### Summary

Continuous rearing of the seed-corn maggot in the laboratory is described. The adults were fed on water, yeast, molasses, evaporated milk, and sugar; the maggots, on germinating peas. Development from egg to adult required 15 to 20 days.

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## Note on Dispersal of Radio-active Grasshoppers<sup>1</sup>

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Riegert *et al.* (1954) showed that nymphs and adults of *Cammula pellucida* (Scudd.) and *Melanoplus mexicanus* (Sauss.) released on bare, cultivated fields, dispersed up to 240 yards during six days. They showed no ability to orient themselves and move toward a food supply. Sixty per cent of *M. mexicanus* were within 50 yards of the release point after seven days. Experiments conducted from the Belleville laboratory in 1952 and 1953 showed that *M. mexicanus* dispersed less widely than this when released in a field population of grasshoppers, mostly *M. mexicanus*, where there was adequate food. This investigation was of special interest to the junior author (R. W. Smith), who was interested in relating the field distribution of adult parasites (as shown by the occurrence of immature parasites in captured grasshoppers) to various environmental factors. The validity of using such data for this purpose would depend upon the movement of the host from the time of parasitization to the time of capture. The following are details of the investigation.

In preliminary tests in 1952, grasshoppers were satisfactorily tagged by feeding them in large screen cages on a mash consisting of 1 pound of bran, 50 millilitres of molasses, and 2 millicuries of P<sup>32</sup> (as H<sub>3</sub>P<sup>32</sup>O<sub>4</sub>) with sufficient water to moisten the mixture. The grasshoppers were fed on the mash for a day, then on fresh grass for a further 24 hours. The interval on the fresh grass

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provided sufficient time for the grasshoppers to excrete any excess phosphorous and thus prevented contamination of the experimental area. Sample counts on individual grasshoppers ranged from 2,000 to 15,000 per minute after this treatment, indicating that the grasshoppers contained sufficient amounts of the isotope to ensure a detectable tag.

In 1953, tagged grasshoppers were released at the centre of a 10-acre field near Chatterton, Ontario: 8,000 in the third and fourth instars on July 8 and 7,500 adults on August 13. A mixed growth of alfalfa, timothy, and weeds provided an adequate supply of food.

Sampling was conducted in four 15-degree sectors marked out from the centre of the field to the cardinal points of the compass. A cage was thrown on the ground ahead of the operator, entrapping all grasshoppers within one square yard. In each sector, two samples were taken at 10 yards from the centre, four at 20 yards, six at 30 yards, and eight at 40 yards. This allowed an approximate correction for the difference in numbers of hoppers attributable to distance from the centre. All trapped specimens were released after being treated for radio-activity. No radio-active grasshoppers were captured more than 30 yards from the release point. Determinations of radio-activity were made with a Tracerlab Survey Meter (Tracerlab Inc., Boston, Mass.) fitted with an end-window Geiger tube.

The numbers of radio-active nymphs recovered at various distances from the release point on various days were as follows:

Days after release					PERCENTAGE
	2	5	13	20	OF TOTAL
10 yards from release point	8	3	9	0	43
20 yards from release point	5	3	6	4	39
30 yards from release point	3	1	4	0	18
TOTAL	16	7	19	4	

Most of the radio-active nymphs recovered were taken within 20 yards of the release point. At the end of 13 days approximately 45 per cent of the nymphs recovered were within 10 yards of the release point and 80 per cent within 20 yards.

The numbers of radio-active adults recovered were as follows:

Days after release							PERCENTAGE
	1	5	8	12	15	18	OF TOTAL
10 yards from release point	49	15	8	11	13	13	56
20 yards from release point	18	13	3	15	6	13	36
30 yards from release point	0	2	3	7	3	3	9
TOTAL	67	30	14	33	22	29	

On a percentage basis, the dispersal of the adults was much the same as the nymphs; over the whole sampling period the majority of the insects were concentrated within 20 yards of the release point. As in the case of the nymphs, adults were not found at 40 yards and only nine per cent of the total recovered were trapped at 30 yards.

In both tests the large numbers of grasshoppers released might be expected to promote dispersal, and the adults no doubt received an additional stimulus from the somewhat denuded condition of the field at the release point. However, the capture of 13 radio-active adults in a single square-yard sample taken at the point of release at the twelfth day revealed a continued high concentration of radio-active adults.

The results show that the range of movement of *M. mexicanus* under conditions of adequate food supply scarcely exceeds 30 yards in three weeks. This is in contrast to its much greater dispersal on bare, cultivated ground.

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### Notes on *Scatophaga stercoraria* (L.) (Diptera: Anthomyiidae), A Predator of the Cabbage Maggot, *Hylemya brassicae* (Bouché)

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During investigations on the life-history and habits of the cabbage maggot, (*Hylemya brassicae* (Bouché), at Charlottetown in 1956, specimens of the dipterous predator *Scatophaga stercoraria* (L.) were observed destroying adults in an outdoor study cage. Identification of the specimens was confirmed by Dr. J. R. Vockeroth, Entomology Division, Ottawa.

In 1957 the predator was taken in collections made in rutabaga fields throughout Prince Edward Island and north-eastern Nova Scotia, and it was often more abundant than *H. brassicae*. It was observed destroying adults of *Coenosia tigrina* (Fall.) as well as of *H. brassicae* in a study cage, and as many as three flies were destroyed in a day by one specimen. As reported by Hobby (1931), the females were observed to be more voracious than the males.

*S. stercoraria* usually stalks and attacks its prey at rest, grasps it firmly between its forelegs, and pierces the cervical region with its mouth parts. It sometimes also punctures intersegmental regions of the abdomen and ingests the abdominal contents. A predator was observed to feed on one fly for as long as 25 minutes, and all of the non-sclerotized contents of the body were ingested. Details of the life-history and habits of the predator are given by Cotterell (1920), and Hobby (1931) reported it as a predator of *H. brassicae* in England.

This is the first record of *S. stercoraria* as a predator of adults of the cabbage maggot in Canada.

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